INTERRELATIONSHIPS BETWEEN SPINAL AND PELVIC ANGLES AND HIP MUSCLE INDICES AND THEIR IMPLICATIONS FOR WORKSPACE DESIGN

by

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PUBLICATIONS

The research reported in this thesis has led to the submission and/or publication of the following scientific papers:

Bridger RS, von Eisenhart-Rothe CC and Henneberg M. (1989). Effects of seat slope and hip flexion on spinal angles in sitting. Human Factors, 31(6):679-688.

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ABSTRACT

The shape of the lumbar and thoracic spinal curves in healthy subjects, when standing and when adopting a variety of working positions, was investigated using angular measures. The hypothesis that spinal and pelvic posture is determined by body position was supported. The mechanism by which body position influences spinal and pelvic posture was investigated using angular indices of the lengths of the hip flexors and extensors. The hypothesis that hamstring stretch determines postural adaptation to sitting positions was not supported. A multivariate analysis revealed that an index of iliopsoas length was the best predictor of posterior pelvic tilt in a variety of sitting positions. A supplementary investigation was carried out using data on the range of motion of the pelvis in the different body positions and its relationship to the muscle length indices. The role of the hamstring muscles in sitting posture was clarified. Some electromyographic data is presented to further illustrate the effect of body position on the role of the hip and trunk muscles in posture.

A replication of the main findings and an investigation of some of the practical implications of the work were carried out drawing attention to some mechanisms of postural stress, potential problems of increased lumbar lordosis and their cost-effective alleviation through workspace design. The provision of a footrest, for example, was found to have significant effects on lumbar and pelvic angles in standing as well as in sitting.

Further research into standing posture in the workplace is indicated by these findings. Some hypotheses for future investigation are presented.

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1. INTRODUCTION

It has long been known that occupational activities such as prolonged daily standing or sitting are associated with an increased incidence of musculoskeletal disorders in the workforce (e.g. Magora, 1972, Kilbom, 1988, Stock, 1991). Much research has been carried out to investigate the stresses imposed on the spines of workers and to relate the imposed stress to the position of the body as determined by the design of the workspace and task (e.g. Nachemson, 1966). In this way, stressful working positions can be identified.

Approaches to the reduction of this stress may take place on one or more levels. Processes may be mechanised or automated to reduce the physical demands on labour. Physiological principles may be used to optimise work-rest cycles or select hardy individuals for a task. Psychological principles may be applied to train workers in more efficient ways of working.

Ergonomics occupies the "no man's land" between those approaches to design which utilise principles from the physical sciences and those which utilise social and biological sciences. An "ergonomic approach" is one in which principles of anatomy, physiology and psychology are applied directly to the design and evaluation of artifacts themselves.

The incidence of occupational low-back pain in industrialised countries is generally regarded as problematic (e.g. Magora, 1972, Nachemson, 1976). A great deal of research has been carried out to develop and evaluate guidelines for the reduction of spinal stress in the workplace. Van Wely (1970) for example provides a useful summary of such guidelines. Much of this work has been inspired by the view that flexion of the spine (particularly the lumbar spine) is to be avoided - particularly when sitting and when lifting objects.

The posture of the spine (particularly the degree of flexion or extension) is held to be of fundamantal importance in determining its ability to withstand loads. Keegan (1953) was one of the first authors to stress the importance of this. A flexed lumbar spine causes "anterior wedging" of the intervertebral discs by the vertebral bodies. This results in posterior protrusion of the disc which then pressurises the posterior ligaments and may cause low-back pain. In pathological conditions nerve roots may be pressurised causing "sciatica". Keegan held that activities which flex the spine are hazardous and increase the probability of disc prolapse as well as chronic low-back pain.

Ergonomic approaches to the reduction of spinal stress have been greatly influenced by this view and by empirical investigations (e.g. Nachemson, 1966, Andersson et al., 1975) which confirm that indices of strain are greater when the lumbar spine is flexed than when it is extended. Keegan held that the lumbar spine is extended (or lordotic) when the angle between the trunk and the thighs was 135 degrees or greater. The loss of the lumbar lordosis at smaller trunk-thigh angles was attributed to passive stretching of the hamstring muscles which, due to their limited length, pulled on the pelvis and tilted it posteriorly when the hip joints were flexed.

Loss of lordosis may also result from shifts in the centre of gravity (C.O.G.) of the body as Bendix et al. (1984) demonstrated in their investigation of the effects of different heel heights on standing posture.

As a result of his analysis, Keegan proposed that chairs should never be designed with the backrest perpendicular to the seat. A rearward sloping backrest was recommended to reduce the amount of hip flexion required of the sitter, thereby reducing the tendency of the lumbar spine to flex. Subsequent authors have accepted the anatomical constraints imposed by Keegan's analysis but have proposed alternative design concepts - the forward-sloping seat of Mandal (1981, 1982) and the industrial stool of Corlett and Eklund (1986) are examples.

Andersson and his colleagues have carried out numerous investigations of sitting (Andersson, 1986, provides a useful review). They also attribute the loss of lumbar lordosis to posterior pelvic rotation and suggest that the hamstring muscles may flatten the lumbar lordosis when the knee is extended. In unsupported sitting, they found a large reduction in lumbar angle (indicating reduced lordosis) compared with standing. A backrest was found to increase the angle (restore some of the lordosis). However, an increase in backrest inclination from 90 degrees to 110 degrees did not increase the lumbar angle, as might have been expected from Keegan's analysis. The postural adaptation to reclining was accomplished by posterior pelvic rotation (extension of the hip joints) rather than lumbar extension.

A lumbar support, extending 4 cm in front of the plane of the backrest, was found to increase the lumbar angle even further. Generally, the influence of lumbar support seemed to be of more importance than that of backrest inclination. The location of the lumbar support in relation to the level of the lumbar spine seemed to be of little importance.

A great deal of research on spinal posture, its relation to body posture and the biomechanical, physiological and electromyographic indices of spinal strain has been carried out (e.g. Corlett et al., 1986). In general, researchers have concentrated on evaluating the effects of different working postures on the spine and other bodily structures in order to identify working positions which are unduly stressful and develop methods of alleviating stress through improved design. Many researchers have begun with an analysis of the effects of loss of lumbar lordosis in sitting or when stooping to pick up an object. The focus has remained on the hamstring muscles as a mechanism of postural adaptation. Little fundamental work on posture itself has appeared in the ergonomics literature. It appears that the hypothesis that postural adaptation to seats depends on length limitations of the hamstring muscles has never been tested directly.

Since Keegan's original paper, new developments have taken place in other scientific domains which have led to an increased understanding of posture in humans. Recent fossil discoveries have clarified the nature of the anatomical adaptations required for early hominids to develop bipedalism and an erect posture (e.g. Tobias, 1982). In the clinical research domain, the first quantitative functional anatomical studies of the erect posture have recently been reported in the literature (e.g. Troup et al., 1968, Toppenberg and Bullock, 1986, 1990).

The general aim of the present thesis was to investigate the functional anthropometry of the spine, pelvis and hip, beginning with the lumbar lordosis as an adaptation to standing. In his original paper, Keegan presented qualitative data obtained from observations of four subjects to demonstrate the effects of body position on the spine and pelvis. Clearly, there is a need to re-examine Keegan's findings using larger samples and a quantitative approach. The present thesis utilised such an approach to investigate the functional anatomy of the spine and pelvis with samples of sufficient size to yield data ammenable to statistical analysis.

The hypothesis that spinal and pelvic posture is determined by body position was tested.

Keegan's description of the mechanism by which body position influences the posture of the spine and pelvis has been very influential despite being restricted to a sagittal view of the body and observations of only four subjects. He held that the anterior and posterior thigh muscles were in a position of balanced relaxation when the angle between the trunk and the thighs was approximately 135 degrees. At larger trunk-thigh angles, the lengthened anterior thigh muscles exerted a pull on the pelvis which tended to tilt it forwards and increase the lumbar lordosis. At smaller trunk-thigh angles the posterior thigh muscles were lengthened and exerted a pull which tended to tilt the pelvis rearwards and flatten the lumbar lordosis. Floyd and Roberts (1958), Mandal (1981), Corlett and Eklund (1984) and Andersson (1986) all refer to the involvement of the hamstring muscles in determining postural adaptation to sitting positions. However, little research in ergonomics has been carried out on the role of the hamstrings in posture.

The hypothesis that hamstring stretch determines postural adaptation to sitting positions was tested, utilising quantitative methods for the evaluation of muscle length.

These methods are frequently used in musculoskeletal research but rarely in ergonomics research and are therefore discussed in some detail in a later section. In the case of the hamstrings, quantitative indices of hamstring stretch are frequently used variously referred to as "range of straight leg raising" (Troup et al., 1968), "straight leg raising" (Pope et al., 1979), "the passive hamstring stretch test" (Fisk, 1979), "hip flexion" (Bridger et al., 1989), and "hamstring length index" (Toppenberg and Bullock, 1990). Despite the differences in terminology, researchers' interpretations of this type of data are essentially similar.

From the above it was hoped that recommendations for workspace design might be derived and new research issues for ergonomics identified.

In the following chapter, previous research on the ergonomics of working postures is reviewed together with the body of scientific work on which it rests. This is followed by a review of recent findings in physical anthropology and functional anatomy from which the present approach was derived.

2. ERGONOMICS OF WORKING POSTURE

The function of the ergonomist is to apply scientific principles to the design and evaluation of man-machine systems in order to enhance the efficiency of the system whilst preserving the health of the workforce.

The application of principles may take place at any stage during the life cycle of a system. Table 2.1 summarises the contribution of the ergonomist as a function of the stage of system development. Most authors agree, however, that the application of ergonomics should begin at the very earliest stages of system design and continue throughout all phases of design and implementation. Huchinson (1981) and Oborne (1982) describe detailed strategies for the inclusion of ergonomic expertise throughout system life cycle. Such strategies are common in the ergonomics literature and fall under the rubric of the "systems approach" to design. The purpose of these systems approaches is to facilitate the management of the design process and to ensure that expertise is brought to bear on a design problem at an appropriate stage during system development.

This applies as much to the investigation of working posture as it does to the investigation of any psychological or physiological aspects of the system which may require ergonomic analysis. In this chapter, a review of the current status of research on the ergonomics of working posture is briefly presented. The emphasis is on the spine and pelvis and the gross posture of the body and the principles of anatomy and physiology which are used to investigate working posture and to measure postural stress. Although detailed anatomical analyses of the limbs have been carried out by ergonomists in order to elicit principles for the design of tools and handles which minimise cumulative trauma disorders such as tendonitis and tenosynovitis (e.g. Kroemer, 1989), these are beyond the scope of the present work.

The Body as a Mechanical System

The human body is a mechanical system which obeys the laws of physics. It consists of a jointed skeleton, muscles, sense organs, an information processing centre (the brain) and "service" systems such as the cardiovascular system. Like any other mechanical system, it may be stable or unstable and is able to withstand a limited range of physical stress. According to Grieve and Pheasant (1982) the term "postural stress" is used to denote the mechanical load on the body by virtue of its posture. "Strain" is the body's various responses to the stress. A rule of thumb used in ergonomics (which appears to have some validity) is that the mechanical efficiency of muscle joint systems is greatest when the joints are in the mid-point of their range of movemement.

Table 2.1

Ergonomics Input in Systems Design

Life Cycle Stage	Ergonomics Input
Analysis	Evaluation of existing technology and user requirements
Planning	Characterise users (develop user profiles)
	Generate and evaluate concepts (value engineering)
Design	User interface design Documentation
Implementation	Ergonomics quality control
Operation	Ergonomics "audit" (post-implementation evaluation)

A great deal of basic anatomical work has been carried out on the spine, particularly the lumbar spine, because of its primary role in supporting the mass of the trunk. The normal development of spinal structures and basic kinematics of spinal motion segments are known (e.g. Kapandji, 1970, White and Panjabi, 1978a, Stagnara et al., 1982, Bogduk and Twomey, 1987). The ability of lumbar motion segments to withstand stress has also been investigated (Yamada, 1970). Adams and Hutton, in a series of papers (e.g. 1983, 1985), investigated many aspects of the stress response of isolated lumbar motion segments as a function of posture. Other investigators have developed biomechanical models of various parts of the musculoskeletal system. Assumptions about the behaviour of the system are made explicit and, where the model fails to predict the system's behaviour, they may be altered in a systematic way to provide new insights into the system. Biomechanical models have been developed for a variety of applications including the analysis of sagittal plane lifting, loads on the low back, and forces at the elbow and hand (e.g. Chaffin and Andersson, 1984).

This research has many applications in ergonomics. It is essential for modelling, in vivo, the stresses on the spine during industrial activities such as lifting and carrying. Techniques such as intradiscal pressure measurement (e.g. Nachemson, 1966a) have been developed to evaluate spinal stress, the intradiscal pressure being an index of load effects from which the imposed stress on the intervertebral discs is inferred. Techniques for the measurement of stature change caused by changes in intervertebral disc thickness have recently been developed to enable the effects of spinal loading to be evaluated non-invasively (Eklund and Corlett, 1984). The rationale of this technique is that intervertebral discs exhibit viscous changes in thickness due to the ingress and egress of fluid in response to changes in the compressive load imposed upon them. The rate of ingress and egress is load dependent in an exponential manner (e.g. de Puky, 1935, Eklund and Corlett, 1984, Bridger et al., 1990). Thus, the rate of stature change can be used as an index of strain. Grieco (1986) suggests that the changes in disc loading which accompany activities of daily living are essential for disc nutrition. Tasks which require operators to adopt static postures may therefore be hazardous, even if the imposed stress is low, since they prevent the normal ingress and egress of fluid from the avascular discs.

The Biomechanics of Standing

The basic limiting condition for postural stability when standing requires that the combined centre of gravity of the various body parts be within the base of support described by the position of the feet (assuming no other external means of support). The main parts of the axial skeleton may be positioned vertically above the base of support. Ideally, the lines of action of the masses of the various body parts should pass through or close to the relatively incompressible bones of the skeleton. The jointed skeleton may then be stabilised in an energy-efficient way by the action of muscles and ligaments which serve merely to correct small, momentary displacements of the mass centres from their bony supports.

The spine is the main support structure of the axial skeleton. Much research has been carried out on the shape of the spine (e.g. Reynolds et al., 1986). Orthopaedic surgeons have long been interested in the identification of abnormal spinal shapes and methods for their correction (e.g. Luque, 1982). Despite the acknowledged importance of the shape of the spine and the existence of various techniques for quantification, none are generally accepted for anthropometric purposes. There is a lack of data on the spinal shapes of healthy populations (Pheasant, 1986).

In stance, the lumbar lordosis is generally considered to position the bony column of the spine close to or directly below the line of gravity of the superincumbent body parts (e.g. Klausen, 1965, Klausen and Rasmussen, 1968, Corlett and Eklund, 1986). This reduces the energy requirements for the maintenance of the erect posture and places the lumbar motion segments in an advantageous posture for withstanding the resulting compressive stress (e.g. Adams and Hutton, 1980, 1983).

However, excessive lumbar lordosis may be a cause of low-back pain. Adams and Hutton (1985) described a mechanism for the aetiology of low-back pain in which hyperlordosis causes the zygapophyseal joints to resist part of the compressive force of spinal loading. Extra-articular impingement may also occur, particularly if intervertebral disc degeneration or compressive loading has reduced disc thickness (Bogduk and Twomey, 1987). This may lead to osteoarthritic changes in the zygapophyseal joints (Adams and Hutton, 1980). Adams and Hutton held that the role of these joints is to resist the shear component of the load, not the compressive component. Avoidance of excessive lumbar lordosis is one way of reducing the compressive load on the zygapophyseal joints.

Physiotherapists and orthopaedic surgeons often advise their patients to place one foot on a footrest when working in order to reduce the lumbar lordosis. In clinical textbooks such as White and Panjabi (1978b), this is often found under headings such as "ergonomic advice". Fahrini (1966), in a popular treatment of the subject, provides practical advice to sufferers of low-back pain, most of which is designed to prevent excessive lordosis.

However, the ergonomics literature contains little or no information on this subject (i.e. the effects of excessive lordosis and design guidelines for its prevention in industry) as suggested by a survey of several contemporary textbooks (Huchinson, 1981, McCormick and Sanders, 1982, Oborne, 1982, Singleton, 1982 and Pheasant, 1986) and design manuals (Croney, 1980, Woodson, 1981 and Clark and Corlett, 1984). McCormick and Sanders illustrated a "sit-stand" workspace which provided a footrest for sitting but not for standing. Most of the attention seems to have been paid to the deleterious effects of loss of lordosis when sitting and when lifting weights.

Support of body mass can be achieved in several different ways. Ideally, the skeleton should play the major role since this is its function. However, muscles, ligaments and soft tissues can also play a role, but at a cost of increased energy expenditure, discomfort or risk of soft tissue injury etc. For example, when, during stance, a person inclines the trunk forwards as if to touch the toes, it can readily be observed that the pelvis moves in the opposite direction to compensate for the forward displacement of the C.O.G. of the body. This maintains the net C.O.G. of the body within the base of support described by the position of the feet. Although stable, this posture places strain on the posterior spinal ligaments and lumbar intervertebral discs since the mass of the upper body is now supported by passive tension in the ligaments and asymmetrical loading (wedging) of the intervertebral discs.

This exercise can be repeated with the person arching the back to produce a different, but still stable, posture. The cost of maintaining such a posture is physiological. The long muscles of the back must carry out static work to maintain the spine in this relatively unflexed position. The cost of this work is fatigue since the contracted muscle tends to occlude its own blood supply. Muscles fatigue rapidly under conditions of static loading (Kroemer, 1970).

In some cases, soft tissues can support some of the mass of the body parts. It has been suggested that the lumbar spine is supported by increased intra-abdominal pressure during manual materials handling. The workings of this "abdominal" mechanism and the manner in which it supports the spine are still under debate (e.g. Gracovetsky and Farfan, 1986, Aspden, 1987) but since the early work of Morris et al. (1961) remote sensing of intra-abdominal pressure has been used as an index of spinal stress (e.g. Stubbs et al., 1987). Ortengren et al. (1981) have shown this method to correlate highly with electromyographic and discometric methods of measuring the postural stress on the spine.

In the case of increased intra-abdominal pressure, a principal cost is interference with normal breathing as the diaphragm has to move against increased presssure on inspiration.

In many cases, the cost of soft tissue support of bodily structures is "pressure ischaemia" resulting in poor blood flow and discomfort. When sitting on badly designed seats, the soft tissues surrounding the ischia may play an unduly great role in supporting the mass of the upper body. If the seat is too high, the soft tissues in the popliteal region may be unduly pressurised due to supporting the weight of the legs.

Engineering Anthropometry

Objective methods exist for the quantification of postural stress, as described above. Anthropometric data are available for the design of workspaces to minimise the imposition of such stress. Anatomical landmarks for the measurement of body segment parameters have been specified and standard anthropometric measurements are available for use in engineering design (e.g. ISO/DIS 7250, 1983). Data concerning the static dimensions of several major populations are available (e.g. Panero and Zelnik, 1979, Pheasant, 1986).

Such data are commonly used in ergonomics to design workspaces to fit the widest range possible of a user population ("fitting the task to the man"). A consideration of possible sources of postural stress (as discussed above) can be undertaken to generate criteria for the application of the anthropometric data. For example, static loading of the spine due to stooping to turn a crank can be minimised by selecting a crank height compatible with the highest standing knuckle height in the population.

Anthropometric data may be used in more sophisticated applications to obtain estimates of the load on different parts of the body (Eklund et al., 1983). The method combines empirical techniques for recording posture (e.g. Corlett, 1979, Grieve and Pheasant, 1982 and Cote-Gil and Tunes, 1989) with "newtonian" anthropometric data concerning limb masses and centres of gravity to provide estimates of postural stress.

Functional anthropometric data are also available. The functional approach goes beyond the measurement of static body dimensions and takes account of the space requirements of the body in motion. The data are usually presented in the form of workspace envelopes which define the limits of body movement from a fixed reference point. The dimensions of the spaces depend not only on the population under study but also on the number of joints involved in the movements used to define the space. The data may be used to ensure that tasks can be carried out comfortably within the available range of movement of the joints concerned and to minimise compensatory involvement of other joints due to unrealistic task requirements. The force output of joints is known to vary with the joint angle (Grieve and Pheasant (1982) and functional anthropometry can be used to ensure that controls and tools etc are positioned in the workplace such that they can be operated optimally (e.g. Pheasant and O'Neill, 1975, Pheasant, 1983).

Postural Behaviour

The body can be considered as a system of linked masses held together by ligaments with muscles as a source of motive power. The conditions for postural stability can be ascertained by considering the relation between the position of the body parts and the base of support. A "comfortable" posture is one in which the body is both stable and supported in an energy efficient way without undue stress on soft tissues and ligaments. As discussed above, principles of anatomy may be used to evaluate postural stress using a variety of objective techniques.

Dempster (1955) viewed the body as an open-chain system of links. Each joint of the body has a freedom for angular motion in one or more directions. A complex linkage, such as that between the shoulder, arm and hand has many degrees of freedom of movement and, when subjected to external or internal forces, will move in complex and unpredictable ways.

Power transmission is impossible without accessory stabilisation of joints by muscle action. For example, supination of the wrist may be required to turn a door handle but this is only possible if the elbow and shoulders are stabilised and can counter the reaction at the hand-handle interface. Thus, it is valid to discuss workload in terms of primary load or the physical work required to manipulate the objects involved and secondary load, the work required to stabilise the joints and support the body in such a way that useful work can be performed. It is noteworthy that many industrial tasks involve the manipulation of objects whose mass is trivial in comparison with the mass of the operator and the body segments used to manipulate them.

In many situations, it may be advantageous to turn the open chains into closed chains thereby reducing the additional energy cost of using muscles to act as "brakes" to stabilise the system. This limits the degrees of freedom of movement and may introduce "coupled" or self-cancelling movements into the chains. Folding the arms and crossing the legs are examples of this. Friction between body parts is normally sufficient to maintain such positions. Branton and Grayson (1967) and Branton (1969) used this approach in the analysis of the comfort of train seats. The prime function of a seat is to support body mass against the forces of gravity. A second function, emphasised by Branton, was to stabilise the open chain of body links. In the absence of stabilisation from the seat, tonic muscle activity is required which leads to discomfort. Hence, behaviours such as folding the arms and crossing the legs are attempts to relax in a stable manner. The comfort of a seat, according to this analysis, depends on the extent to which it permits muscle relaxation while stabilising the open-chain system.

Finally, body link analysis explains certain principles underlying manual skill and the ability to exert large forces on the environment. According to Dempster, when the body forms a closed system of links to exert forces on the environment, the trunk and limb muscles do not exert forces directly, rather they maintain joint postures such that body weight can be used to exert an effective moment. This mechanism undoubtedly makes possible those activites in which joints, body segments or external objects undergo rapid acceleration through "pivoting" actions (as in throwing a javelin or swinging a golf club).

Fatigue and Discomfort

A major goal of research into working posture is to develop principles for the design of work environments low in postural stress in order to reduce the incidence of fatigue and discomfort. An early investigator (Vernon, 1924) concluded his investigations of fatigue amongst factory workers with the statement that "any form of physical activity will lead to fatigue if it is unvarying and constant".

Little information exists on the causes and nature of discomfort. At the most simple level, discomfort may be seen subjectively and defined as the absence of comfort. Clearly, this is inadequate and research suggests that the question of discomfort can be addressed in at least 4 different ways and that investigations should take place at a number of levels (Eklund and Corlett, 1986).

Branton (1969) suggests that discomfort results in an "urge to move" caused by a number of physiological and physical factors and, therefore, has behavioural manifestations. Pressure on the ischia and surrounding tissues caused by the contouring and constriction of a seat can influence comfort and can be measured using pressure transducers. McCormick and Sanders (1969) discuss weight distribution in the context of seat design and present data on the desirable distribution of pressure in the form of an equal pressure contour diagram. Apart from skin pressure, discomfort can also arise due to static loading of ligaments and joint surfaces and pressure ischaemia.

Discomfort may be of muscular origin. Even low-level muscular activity can lead to fatigue if it is unvarying. As Nachemson (1968) has pointed out, the spine itself lacks intrinsic stability and depends on muscle activity for stabilisation. According to Branton (1969) this lack of inherent stability and the importance of the trunk muscles is clearly demonstrated when an attempt is made to hold an unconscious person upright. However, the presence of this type of muscle activity is not always easily detectable using techniques such as electromyography (EMG). For this reason, observation of postural behaviour may be a useful source of data on comfort and discomfort. Several methods of quantifying postural behaviour have been developed with some success notably "posture targetting" (Corlett, 1979).

Psychological methods may also be used to obtain information on discomfort. Perceived discomfort may be referred to a part of the body using "body diagrams". These are sometimes used in conjunction with rating scales to indicate the degree of discomfort. Alternatively, ratings of discomfort may be made in relation to the design of chairs and workspaces using questionnaires (e.g. Shackel et al., 1969) and to determine users' preferences for design (e.g. Grandjean et al., 1984).

For present purposes, the discussion of fatigue may be restricted to its musculoskeletal aspects (although it is permissable to talk about decrements in task performance due to "mental" fatigue). According to Grieve and Pheasant (1982) some experiments indicate that muscle fatigue results from depletion of metabolites in a muscle whereas there is other evidence indicating that accumulation of metabolic waste products is the cause. Waste product accumulation can occur as a result of diminished blood flow during forceful, particularly isometric, contractions.

Electromyography, using skin or fine wire electrodes, has been used to detect muscle fatigue. It has long been known that the frequency content of the myoelectric (ME) signal appears to shift towards the lower frequencies as a sustained contraction progresses to exhaustion. Stulen and DeLuca (1982) briefly reviewed theories of muscle fatigue in relation to ME activity and concluded that spectral compression occurs as a result of a decrease in conduction velocity caused by the accumulation of metabolic by-products. They developed a device for tracking spectral change during muscle contraction. The device, known as the muscle fatigue monitor, calculates the median frequency of the ME signal over time. This information may be presented as a time series of median frequency. An interesting variation on this technique is to take the initial median frequency as a cut-off and express the rms value of the activity below the median (the low-rms voltage) as a ratio of the rms of the activity above the median (the high-rms voltage). This parameter increases in magnitude as the muscle fatigues.

Electromyography is commonly used in ergonomics to detect localised muscle fatigue when evaluating the stressfulness of tasks and when comparing design alternatives and evaluating improvements (e.g. Malmqvist et al., 1981, Bendix et al., 1985). A useful introductory review of electromyography and some of its uses may be found in Soderberg and Cook (1984).

Ergonomics of Sitting

Two models of the anatomy of sitting have influenced seating research. The first is derived from the work of Keegan (1953) and the second from Dempster (1955) via Branton (1969) and Corlett and Eklund (1986). They may be outlined as follows.

The design of workspaces for seated operators has long been based on a sitting position in which the angle between the trunk and the thighs is approximately 90 degrees. As Keegan (1953) pointed out, this posture is only partially achieved by flexing the hips. He maintained that, in sitting, the hip joint flexes by approximately 65 degrees. The hamstring muscles pull on the pelvis causing it to rotate posteriorly. This flattens the lumbar lordosis. Thus, the postural adaptation to sitting takes place partly in the hip joints and partly in the lumbar spine. The C.O.G. of the upper body parts moves anteriorly with respect to the lumbar spine when the lordosis is lost. This increases the flexion moment on the lumbar spine and increases disc compression (Brunswic, 1984).

The increased flexion moment is resisted by passive stretching of the posterior spinal ligaments and asymmetric loading ("anterior wedging") of the intervertebral discs causing them to bulge posteriorly further pressurising the ligaments and possibly nerve roots. Keegan maintained that this was the mechanism of occupational low-back pain which is particularly common amongst middle-aged sedentary workers. Attempts to restore the lumbar lordosis (to "sit-up straight") are usually unsuccessful because of the static muscle work required.

In sitting, the weight of the upper body is supported by the ischial tuberosities. Branton (1969) viewed the ischial tuberosities as a two-point base of support which is unstable sagittally. Unless the pelvis or the top of the sacrum was externally stabilised, posture would vary as the pelvis "rocked" on the ischia. Since the ischia are posterior to the hip joint, the pelvis must rotate posteriorly if the ischial base of support is to be positioned below the C.O.G. of the trunk.

A seated person tends, therefore, to slump as the pelvis tilts rearwards or the trunk is inclined forwards and the person stabilises the upper body by resting the elbows on a desk or bench. The function of a backrest, according to this analysis, is to stabilise the upper body in an erect position (Corlett and Eklund, 1986). However, the lumbar spine remains flexed. Some modern chairs have "lumbar supports" - protruberances in the backrest at the level of the upper sacrum and lumbar spine - which tilt the pelvis forwards to restore the lumbar curve thereby reducing the flexion moment on the spine.

The unsupported sitting position is never as stable as standing. Many of the muscles which control the posture of the trunk are attached to the femur. If the femurs are not stabilised by weight bearing, as in standing, these muscles cannot function effectively.

In practice, the working posture of a seated person depends on several other factors over and above the basic postural adaptation to the seat. The visual and manual requirements of the task, the design of the rest of the workspace and the anthropometric and postural habits of the individual all influence the range of postures that can be adopted within the anatomical constraints imposed by the basic design (e.g. Floyd and Roberts, 1958, Mandal, 1981, Bridger, 1988).

Design and Evaluation of Seats

Anatomical analysis has led several authors to propose concepts for chair design and to evaluate them by observing the sitting posture, particularly the posture of the spine, accompanying their use.

Keegan maintained that the neutral position of the hip joint, defined as the position which gave rise to balanced relaxation of the hip flexors and extensors and an absence of anterior or posterior tilting moments on the pelvis, was obtained when the angle between the trunk and the thighs was approximately 135 degrees. Further, he maintained that, ".....rotation of the pelvis by the posterior thigh muscles in the right-angled sitting position is a greater determinant of the obliteration of the lumbar curve than is the presence or absence of low back support or the position at the knees". Thus, trunk-thigh angle was regarded as the key consideration in the design of seats.

This led Keegan to propose that the backrest of a seat should recline by at least 15 degrees from the vertical to provide a minimum trunk-thigh angle of 105 degrees. Keegan believed that this would eliminate 15 degrees of the lumbar flexion required to sit. It is noteworthy that Keegan placed less importance on the position of the knees as on the trunk-thigh angle despite considering the hamstrings (a two-joint muscle shortened by knee flexion) to make the major contribution to the loss of the lumbar lordosis in sitting.

Many tasks require the maintenance of an erect trunk, however. Mandal (1981, 1982) suggested that seats should slope forwards to enable the upright position of the upper body to be held whilst the angle between the trunk and the thighs remains greater than 90 degrees. Mandal described the base angle of the spinal column as the angle made by the horizontal and a line running through a fifth lumbar disc (Figure 2.1). Based on Schoberth's (1962) view that "in the upright sitting position we have never seen a lumbar curve where the base angle was less than 18 degrees. Conversely, a rounded back has never been found where the base angle was more than 10 degrees", Mandal described how the base angle might be increased by 20 degrees if the seat was tilted forwards by 20 degrees. A rudimentary form of forward-sloping seat might be obtained by placing a firm cushion under the ischia, according to Mandal.

The shift in design philosophy away from the "90-degree" sitting posture to a "110-degree" posture has produced three classes of alternative seat. The first is derived from Keegan and is essentially conventional with attention given to the design of a backrest for reclining against. A lumbar support, which uses the lumbar spine as a lever to tilt the pelvis forwards to restore an alignment similar to standing, is sometimes incorporated (Keegan, 1962). The second is derived from Mandal (1981) and consists of a forward-sloping seat for upright work (sometimes fitted with "kneepads" to provide fore-aft stability). The third consists of "sit-standing" aids - seats designed to support a posture half-

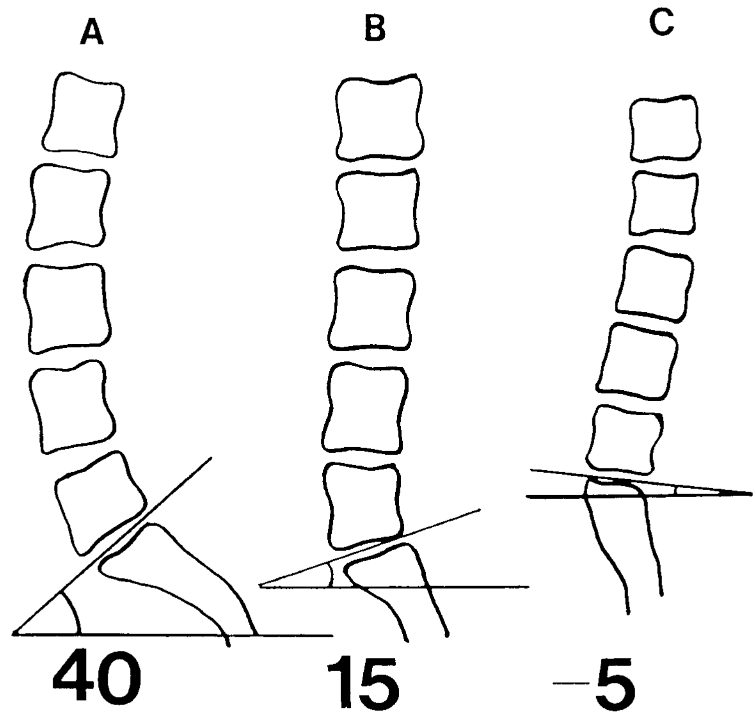


Figure 2.1 The relationship between base angle and lumbar curvature (adapted from Mandal, 1981).

(a) Base angle 40 degrees with lumbar lordosis

(b) Base angle 15 degrees with no lumbar lordosis

(c) Base angle -5 degrees with no lumbar lordosis way between sitting and standing (see Gregg and Corlett, 1988 for an industrial example and Bendix et al., 1985, for an example of a "saddle-seat").

Evaluation and Characterisation of Standing and Sitting Postures

Empirical investigations of seats based on the "110-degree" concept indicate that their use is accompanied by less flexion of the lumbar spine than conventional seats (Bendix and Beiring-Sorensen, 1983, Frey and Tecklin, 1986 and Bridger, 1988). The lumbar spine retains a posture midway between the lumbar lordosis found in standing and the flattened posture found in "90-degree" sitting.

However, Bendix et al. (1983) demonstated that changes in the base angle do not necessarily lead to increases in lumbar angle in a simple manner. They found that two-thirds of the postural adaptation to forward-sloping seats (compared with conventional seats) was hip extension rather than lumbar extension. As far as seat slope was concerned, increased slope did not necessarily lead to increased lumbar lordosis. As these authors point out, postural adaptation to a forward-sloping seat can take place in several ways - the whole trunk can tilt forwards in correspondence with the slope resulting in no change of joint alignment, the hip joints may extend accordingly or the lumbar spine may extend.

Corlett and Eklund (1986) and Gregg and Corlett (1988) have criticised the use of forward-slope in chair design because it introduces a horizontal force component which destabilises the sitter and has to be resisted by the lower body (they maintain that for comfort and to avoid fatigue, no more than one-third of body weight should be borne by the feet in sitting). The horizontal force component may also cause tightness in clothing as the sitter slides forwards. Some forward sloping chairs are fitted with kneepads to resist the horizontal force component. They are not a general design solution, however, because the kneepad may introduce discomfort due to static loading of the knees (Drury and Francher, 1985) and is probabaly unsuitable for those with previous knee injury or disease (Bridger and Jaros, 1986). Corlett and Eklund argue that the effect of a forward-sloping seat can be obtained equally well by means of contouring such that the ischia rest on a horizontal surface (thus eliminating the horizontal force component) while the hips are still free to extend because only the under-thigh portion of the seat slopes downwards. This enables an "open" trunk-thigh angle to be obtained while avoiding several of the practical problems introduced by the use of forward slope.

This argument is valid if the effect of a forward slope is to reduce the hip flexion required to sit and if the reduced hip flexion results in increased lumbar lordosis. However, forward slope may have additional effects, for example causing the pelvis to "rock" forwards over the ischia in which case the approach might not be as effective as expected. These possibilities may be tested empirically.

Most research on seating compares an experimental seat with a small number of alternatives, usually a conventional seat and standing. Although it is known that the shape of the spine determines its ability to withstand load, it cannot be said, for example, that sitting on a forward sloping seat is any different (from the point of view of the lumbar spine) than sitting on the edge of a desk or kneeling (other considerations, such as general comfort are beyond the scope of this work).

A second set of problems concerns the use of measures of central tendency to describe differences between the lumbar angles of subjects sitting in various types of seats or standing - natural variability in posture and postural adaptation tends to be ignored. This has important practical implications since ergonomists do not use measures of central tendency in design - rather they employ critical dimensions at one or other end of a distribution (usually fifth or ninety fifth percentiles). For example the critical dimension in establishing the maximum height of a seat of fixed height is the popliteal height of a short user (usually a fifth percentile adult female).

Measures of central tendency do not illuminate individual differences in postural adaptation. For example, when comparing the lumbar spines of subjects sitting on each of two experimental chairs the mean difference in lumbar angle may be 10 degrees but for some subjects, the difference may be 20 degrees - for others there may be no difference at all and no explanation for the variable postural adaptation of the subjects.

Summary

The above discussion presents a broad review of research into the ergonomics of working posture, the concepts which have influenced researchers, some of the techniques commonly used and the issues investigated.

Basic principles of anatomy and physiology are clearly essential tools for the critical evaluation of workplaces and the formulation of valid design concepts.

It is perhaps surprising therefore that little data on the anthropometry of the spine are available - particularly in view of the practical importance of this information for evaluating the postural stress of particular working positions and, for example, for designing appropriate backrest contours for seats in vehicles and in industry. Recent developments in the mechanical modelling of spinal stress further support this. Aspden (1989) has proposed a new approach using techniques developed for the analysis of the mechanical stability of masonry arches. In this approach, the shape of the spine is fundamental and has a major influence on the magnitude of the compressive stresses estimated by the model.

The spine is a complex, morphologically dynamic structure - its shape is dependent on the position of other body parts. This is one reason for the lack of data on spinal posture and its variability.

In the following section, some fundamental aspects of posture not commonly encountered in the ergonomics literature are reviewed. The present approach was derived from a consideration of these aspects of posture.

3. SOME FUNDAMENTAL ASPECTS OF POSTURE

When applying anatomical principles to the practical evaluation of working conditions, an operational definition of posture is usually adequate. Grieve and Pheasant (1982) for example define posture as "the average orientation of the body over time". Methods for recording the gross positions of the main body parts such as "posture targetting" (Corlett 1979) can be used to evaluate the "anthropometric fit" between workers and their surroundings. This data can be supplemented using biomechanical, electromyographical and radiological analyses to identify postural stress caused by anthropometric mismatches and used to suggest improvements (e.g. Colombini et al., 1986).

For present purposes, however, a deeper view of posture was required. Recent research in physical anthropology and clinical functional anatomy is briefly reviewed below. This research contains the conceptual framework and experimental methodology on which the present work was based.

Physical Anthropology of the Erect Posture and Hominid Evolution

The upright posture and bipedal mode of locomotion that characterises Homo sapiens has a long evolutionary history. Comparative analysis of the anatomy of early hominids, Homo sapiens and modern great apes can help specify the adaptations required for the adoption and maintenance of the upright posture and, indeed, clarify what is meant by the term posture as it is used in ergonomics.

Figure 3.1 depicts the bipedal posture adopted by a human and by a chimpanzee. In the chimpanzee, the C.O.G. of the body lies anterior to the lumbar spine and hip. In the human, it lies

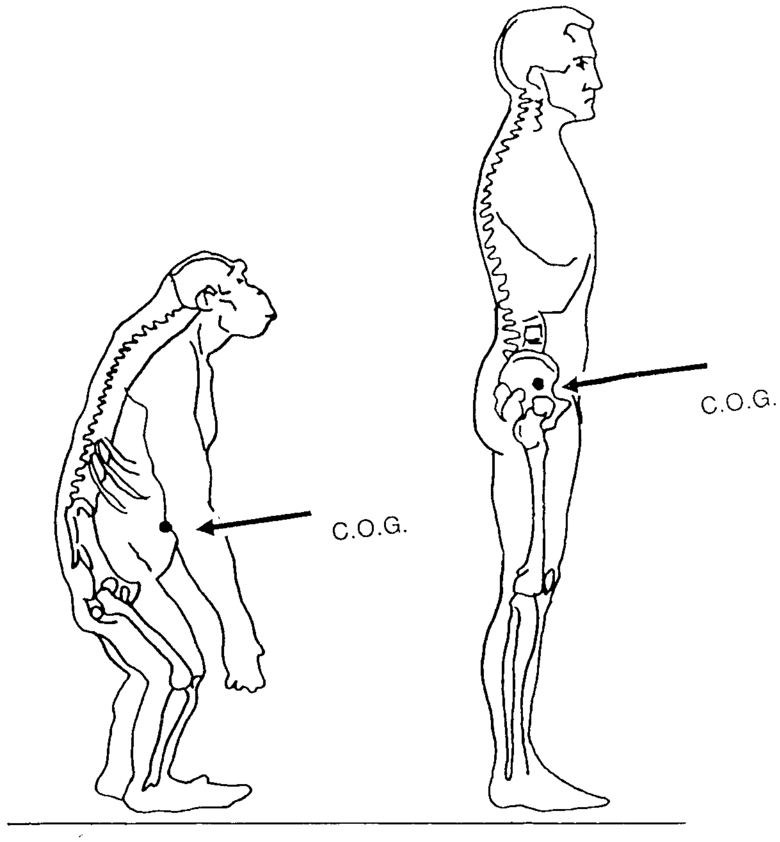


Figure 3.1 The bipedal posture in man and chimpanzee - note the location of the centre of gravity (C.O.G.) of the body in relation to the hip joint (adapted from Zihlman and Brunker, 1979).

above the hip joint. This reduces the mechanical disadvantage of the gluteal muscles in keeping the trunk erect. Note also that the chimpanzee has limited hip extension and cannot extend the hip to place the femur perpendicular to the ground. This is due to length and position of the ischium. In evolutionary terms, the main anatomical adaptations to bipedalism can be summarised as follows (see Robinson, 1972, Zihlman and Brunker, 1979, McHenry and Temerin, 1979 and Tobias 1982 and, for more popular treatments of the subject, Napier, 1967 and Lovejoy, 1988):

The lowering of the <u>relative</u> C.O.G. of the body by means of a broadening and flattening of the ilium and sacrum and a shortening of the arms and a lengthening of the legs is a basic adaptation to bipedalism which reduces the energy requirements for the correction of momentary displacements of body mass.

The function of the gluteal muscles differs between hominids and modern apes. In apes, gluteus medius and gluteus minimus are major hip extensors used for locomotion while gluteus maximus is of minor importance. These muscles are attached to the iliac blades and the upper femur. In chimpanzees, the iliac blades are flat and lie across the back of the torso in a <u>single plane</u> (Figure 3.2), whereas in hominids (including Homo sapiens), the ilium is rotated <u>forwards</u> around the body. This displaces the anterior gluteals into a lateral position on the body and converts them to hip abductors. Gluteus maximus remains posteriorly positioned but exhibits hypertrophy. In hominids, its function is no longer locomotion but to stabilise the trunk and prevent it "jacknifing" forwards over the legs when walking. The sacrum widens to leave room for the viscera and birth canal.

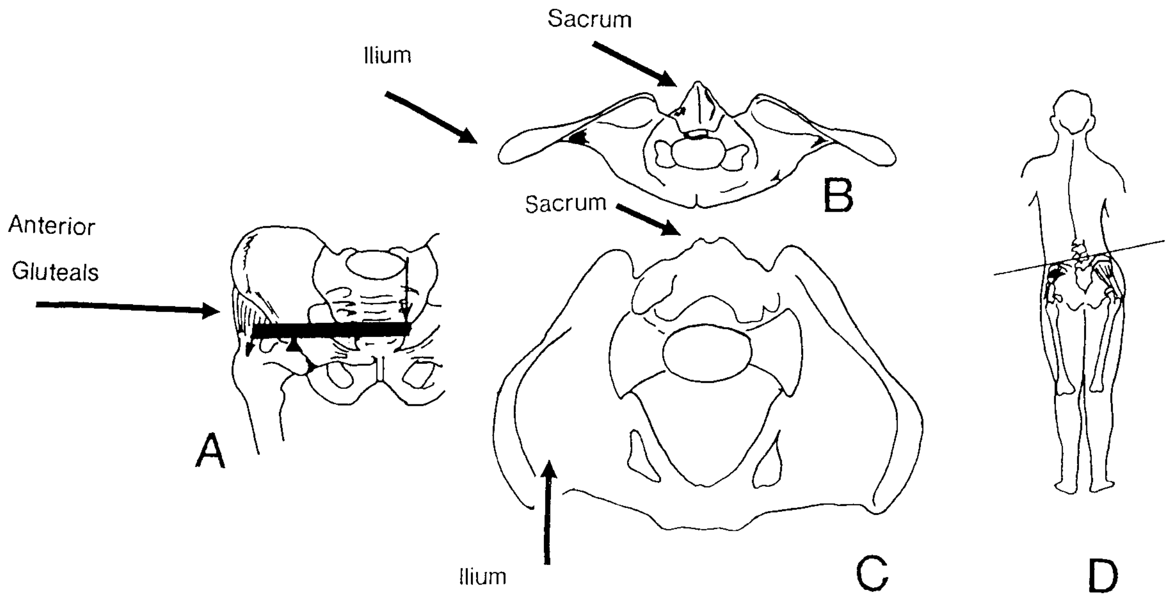


Figure 3.2 The hip and pelvis related to posture.

(a) Frontal view of human pelvis and hip joint. The joint acts as a fulcrum during walking. The anterior gluteals, acting as hip abductors, counteract the moment exerted by the upper torso and unsupported leg.

(b) Top view of the pelvis of a chimpanzee. Note that the iliac blades lie almost flat, in a single plane. The gluteal muscles act as hip extensors in the chimpanzee.

(c) Top view of a human pelvis. Note the curved ilia which provide lateral attachment points for the anterior gluteals, enabling them to abduct the hip.

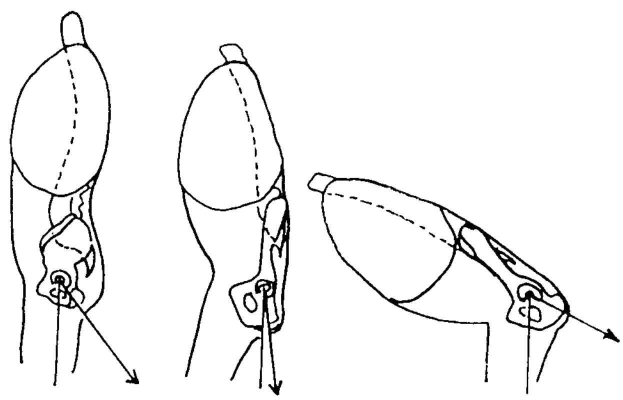
(d) "Trendelenburg" posture. Weakness of the right anterior gluteals causes deviation of the pelvis to the right and lateral tilting to the left. The spine exhibits compensatory scoliosis. This type of posture can also be observed when people stand on an uneven surface to work.

(adapted from Lovejoy, 1988 and Kendall et al., 1971).

For part of the bipedal gait cycle, the pelvis is only supported on one leg. To stabilise the upper body, the re-orientated anterior gluteals act as hip abductors. Viewed frontally, it can be seen that the hip joint acts as a fulcrum with the weight of the body and the unsupported leg exerting a moment on one side which is counteracted by the abductors on the other (Figure 3.2). In hominids, the femoral neck is lengthened and the ilium is flared outward, away from the body to increase the lever arm of the hip abductors. Patients with weak or paralysed hip abductors exhibit the "Trendelenburg" gait in which the pelvis tilts towards the unsupported leg and the upper body bends towards the supported leg in compensation.

The ilium is also expanded posteriorly, bringing the C.O.G. of the body closer to the hip joint in the sagittal plane.

In order to stand erect, the spine must be repositioned from horizontal in the quadrupedal posture to vertical in bipedal posture. This cannot be achieved by simply rotating the pelvis on the vertical femur by 90 degrees until the trunk is erect because the extension of the femora required for walking (i.e. extension past the vertical by the trailing leg) is then impeded by the ischium. This is one reason why the great apes cannot walk on two legs efficiently (Figure 3.3). Further, the sacrum cannot be rotated <u>backwards</u> with respect to the ilium. Although this would help to place the spine in a vertical position, while using less than 90 degrees of hip extension, the birth canal would then be obstructed by the coccyx. Somewhat counterintuitively, the evolutionary solution seems to have been to rotate the sacrum <u>forwards</u> on the ischium and increase the extension of the lumbar spine. This is the origin of the lumbar lordosis which is of so much concern to researchers in seating. According to



A B C

Figure 3.3 Orientation of the ischium with respect to the hip joint.

(a) Man standing erect.

(b) Chimpanzee standing erect.

(c) Chimpanzee in normal quadrupedal posture.

In (b), the ischium prevents extension of the thigh past the vertical. Comparison of (a) and (c) reveals the fundamental nature of the lumbar lordosis as an adaptation to erect bipedalism.

(adapted from Robinson, 1972).

Farfan (1978), the posterior lumbar (supraspinous) ligaments and the zygapophyseal joints of the fourth and fifth lumbar vertebrae are specially adapted in man to resist the lumbosacral shear force which is bought about by the anterior tilt of the sacrum and which is exacerbated when objects are lifted.

The pelvis can be seen as the base on which the spine is supported. Many muscle groups which, in other species, provide locomotive power take on new roles in the bipedal posture. As described above, the anterior gluteals now stabilise the pelvis. The iliopsoas muscles initiate "swing-through" of the trailing leg in walking and the hamstrings decelerate it prior to heel strike. Only the quadriceps and the plantarflexors (gastrocnemius and soleus muscles) are left to provide a ground reaction force for locomotion in walking.

The fossil record provides considerable insights into the evolution of the upright posture over time and the anatomical adaptations which bipedalism requires (interestingly, as Kapandji, 1970, points out, the true physiological position of the hip in man corresponds to the position on all fours. In standing, the head of the femur coincides imperfectly with the acetabular cavity. This is used to argue in favour of man's evolution from quadruped ancestors). According to Farfan (1978), the lumbar lordosis and other adaptations provide an overabundance of power for attaining the upright posture. The erection of the trunk has been achieved only partly by the backward rotation of the pelvis the rest by the inversion of the normal quadrupedal lumbar curve (concave anteriorly) into a lumbar lordosis (concave posteriorly).

Anatomical Aspects of the Hip and Pelvis Related to Posture

In erect standing, as has been described, only part of the erection of the trunk is accomplished by extension of the hip joint from the quadrupedal posture. The rest occurs as extension (lordosis) of the lumbar spine. This means that the pelvis is tilted anteriorly, relatively speaking, in normal standing.

The antero-posterior tilt of the pelvis has a major influence on the posture of the body since it co-varies with the angle of the sacrum from which the lumbar lordosis arises. An understanding of factors influencing tilt of the pelvis is therefore essential for the analysis of posture and postural load.

In Figure 3.4, the pelvis is represented sagittally with the hip joint regarded as a fulcrum. In the normal standing posture, the line of gravity of the superincumbent body parts falls posterior to the centre of the acetabula. Most of the weight transmission occurs through the posterior pelvis causing a posterior rotation force downward, around the acetabula. Thus, pelvic tilt during stance does not require the support of the the abdominal muscles (DonTigny, 1985).

The tilt of the pelvis is the equilibrium position of the moments and countermoments exerted by body weight and the muscular-ligamentous system which fixes the pelvis on the hip joint. The iliofemoral ligament lies anterior to the hip joint and the ischiofemoral ligament lies posterior to the joint. In standing, these ligaments are in moderate tension. During extension of the hip, all of the ligaments become taut whereas in flexion they relax. In standing, the iliofemoral ligament prevents the pelvis from tilting posteriorly i.e. it prevents the trunk from "jackni-fing" backwards over the legs.

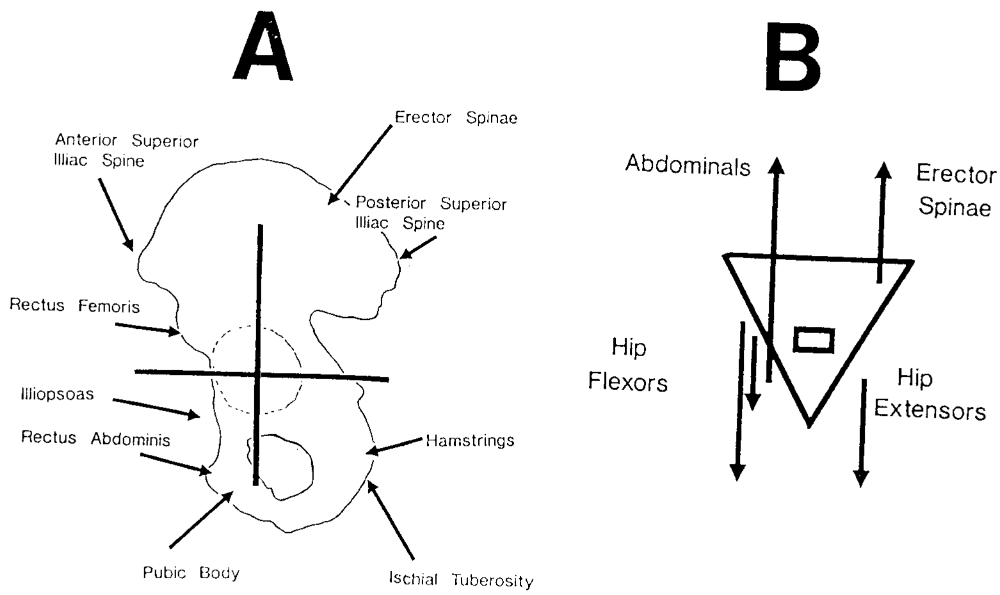


Figure 3.4 Conceptual model of the sagittal pelvis. Arrows indicate approximate attachment areas/points of action of muscles in A and idealised vertical components of muscle forces in B. For illustrative purposes, the following moment arms (distance from point of action to hip joint centre) were estimated using specimen pelves.

Muscle	Attachment Area*	Moment Arm (mm)	
		Male	Female
Rectus Femoris	Anterior Inferior Iliac Spine	45	25
Iliopsoas	Superior Ramus of Pubis*	27	25
Erector Spinae	Sacro-iliac region	70	54
Rectus Abdominis	Pubic Symphysis	60	60
Hamstrings	Ischia	45	25

* Or estimated point of action

During lateral rotation of the hip (to stand with the toes pointing outwards, for example) the anterior ligaments become taut and the posterior ligament slackens. The opposite occurs during medial rotation (Kapandji 1970). This may explain why Cyriax (1924) held that walking with the toes turned out too much was a cause of excessive anterior pelvic tilt in children (and hence excessive lumbar lordosis). This would slacken the posterior ligament and tense the anterior ligaments resulting in a net increase in the anterior moment acting on the hip joint and a more anteriorly tilted equilibrium position of the pelvis. This suggests that an analysis of foot position is essential to the analysis of posture and the improvement of the design of workspaces.

Pelvic tilt is not the only determinant of spinal curvature. Kapandji (1970) describes how the articular facet of the sacrum is subject to wide variation in humans. In the more horizontally aligned sacrum, the spinal curves are pronounced - Kapandji regards this as an overadaptation to the biped state. When the sacrum lies more vertically on the ilium the spinal curves tend to be less pronounced. Although the more vertically aligned sacrum with flatter spine does occur in adults, it is more usually seen in children and more closely resembles the sacral orientation found in primates (Kapandji, 1970).

In neonates, the spine exhibits a single, anteriorly concave curve and vertical sacrum. This <u>kyphosis</u> of the lumbar spine disappears at about 13 months of age and is replaced by a lumbar lordosis of increasing severity after the third year. By ten years, the adult state is assumed. When an adult stands, the lumbar lordosis supports the upper body so as to minimise the bending moment on the spine and the line of gravity of the superincumbent body parts passes through the facet joints of L4 and L5 (Klausen and Rasmussen, 1968).

Development of the bipedal posture in children suggests a recapitulation of phylogeny in ontogeny. The young child is physically unable to stand at first, partly because of an inability to fully extend the knee and hip, and must first develop hip extension by crawling before standing is possible. Raff (1962) regarded premature standing as a cause of maldevelopment of the feet in children.

The Maintenance of Posture

The importance of the anterior gluteals in the lateral stabilisation of the pelvis has already been noted. Figure 3.4 presents a sagittal view of the hip and pelvis. The flexor and extensor muscles of the hip and trunk play a major role in the maintenance of the erect posture. As described above, the pelvis is fixed on the hip by a system of muscles and ligaments. The tilt of the pelvis depends on the equilibrium of the moments and countermoments exerted by the antagonistic muscles in this system. The hip flexors (iliopsoas and rectus femoris) and the hip extensors (gluteus maximus and the hamstrings) are of relevance to ergonomics as are the abdominal and erectores spinae muscles of the trunk. Contraction of the hip flexors (on a fixed femur as in standing) and the erectores spinae tends to tilt the pelvis forwards and exaggerate the lumbar lordosis whereas tension in the hip extensors and the abdominals tends to tilt the pelvis posteriorly and reduce the lumbar lordosis.

The spine itself lacks intrinsic stability. Nachemson (1966b, 1968) notes that an isolated ligamentous spine can only support a load of 2kg placed on top of the first thoracic vertebra.

Klausen (1965) held that the short, deep muscles of the back supported the individual joints of the spine. The long back muscles were responsible for the stabilisation of the spine as a whole when the line of gravity of the upper body parts passed ventrally to the lumbosacral joint. The anterior abdominals stabilised the spine when the line of gravity was dorsal to the axis of movement of the joint.

Nachemson (1966b, 1968) investigated the role of the vertebral portion of the iliopsoas muscle (psoas major) in the extrinsic stabilisation of the spine. He concluded that, in addition to its function as a hip flexor, the psoas muscle was involved in the stabilisation of the lumbar spine, particularly in upright standing and unsupported sitting (i.e. without a backrest). Psoas activity decreased when the trunk was inclined forwards while activity of the sacro-spinalis muscles simultaneously increased. Taken together, and recalling the comments made previously about the function of gluteus maximus, the muscles of the hip and trunk can be seen as a system of synergists and antagonists which influence the shape of the spine in erect standing and sitting through their effects on the tilt of the pelvis as they act to stabilise the upper body.

The abdominal muscles (rectus abdominis and oblique) and the thoracic (intercostal) muscles play a major role in stabilising the spine when a weight is lifted (in relaxed standing they are electromyographically silent), according to the cantilever analysis of Morris et al. (1961). The contraction of these muscles pressurises the contents of the thorax and trunk and converts them into approximate hydraulic and pneumatic "splints" or cylinders capable of resisting some of the flexor moment on the spine and therefore reducing tension in the extensors of the spine.

Aspden (1989) proposed a new mathematical model of the spine based on arch mechanics. In this model, intra-abdominal pressure is essential for lifting heavy weights in conjunction with lumbar lordosis. Empirically, Ortengren et al. (1981) have demonstrated high positive correlations between measures of intra-abdominal and intra-discal pressure and back muscle activity. This does not necessarily imply that intra-abdominal pressure exerts an extensor moment about the spine, however. Aspden proposes that it applies a compressive stress to the convex surface of the lumbar lordosis which acts to stiffen it in the same way that placing a load on an arch increases the stability of the arch.

Postural Faults and Muscle Balance

Kendall et al. (1971) present analyses of postural faults which illustrate the role of the muscles of the hip and trunk in the maintenance of posture. They make considerable use of the concept of "muscle balance" in the analysis of posture. When a muscle is weakened and its antagonist is not, a state of imbalance is said to occur. The stronger muscle then shortens and the weaker elongates resulting in a deformity of the posture of the joint (Figure 3.5 illustrates this using examples of imbalance in the hip and trunk musculature). Weakness results in a lack of support about the joint and permits a state of deformity whereas shortness creates the deformity. Deformities can also occur if weak muscles are no longer able to adequately oppose gravity.

Fisk and Baigent (1981) found that young patients with back pain frequently had stiffness in the lower thoracic spine and this was related to "tight" hamstring muscles (i.e. in these patients, straight leg raising was limited to about 30 degrees due to passive stretching of the hamstrings which prevents further

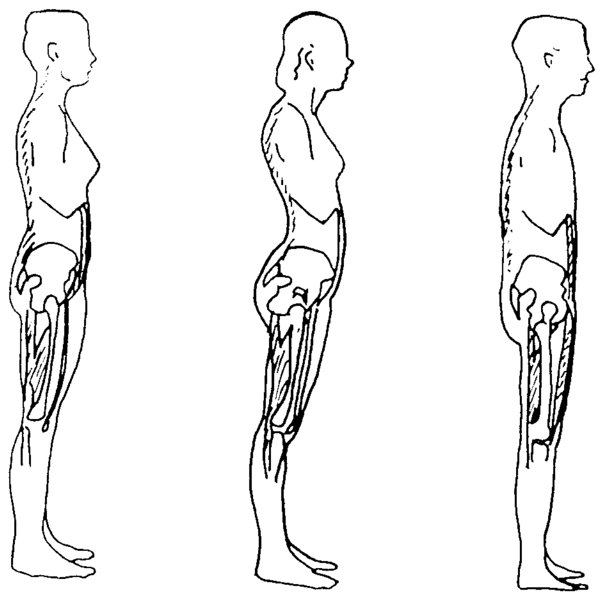


Figure 3.5 Alignment of the spine, pelvis and hip in standing.

(a) Normal posture.

(b) Excessive anterior pelvic tilt and hyperlordosis. The hip flexors and low-back muscles are shortened and the abdominals are lengthened and often weak.

(c) "Flat-back" posture caused by excessive posterior pelvic tilt (hyperextension of the hips). Sometimes caused by weak hip flexors.

(adapted from Kendall et al., 1971).

flexion). They hypothesised that the tight hamstrings, by limiting hip flexion when the knees are extended, would increase the stress on the spine when bending (i.e. flexion of the spine would need be increased to enable activities involving bending to be carried out - trunk flexion being substituted for hip flexion).

DonTigny (1985) describes how activities which require trunk flexion (working at a counter, washing dishes etc) cause the weight of the trunk to shift over the anterior pelvis. If the abdominal muscles cannot oppose the anterior rotation force (due to weakness for example) a lordotic standing posture results. The innominates move anteriorly on the sacrum, loosening the posterior ligaments of the sacrum and rendering it vulnerable to dysfunction or injury. The sacrum spreads the innominates (because it is wider anteriorly than posteriorly) and may cause them to wedge or bind. DonTigny suggests that many complaints of pain in the low-back arise from abnormal pelvic tilt which places rotation strain on the sacro-iliac joint.

A small number of studies have been carried out to investigate the anthropometry of the hip and trunk musculature and the pelvis and spine as a linkage in healthy subjects. Toppenberg and Bullock (1986) carried out multiple regression analyses of thoracic and lumbar angles (of standing subjects), pelvic tilt and indices of muscle length of adolescent females. They found some significant relationships between these variables; in particular a negative correlation between the index of hamstring length and the lumbar lordosis. This suggested that individuals with short hamstrings had more pronounced lumbar lordoses than those with long hamstrings - somewhat surprising since the hamstrings cause posterior pelvic tilting which flattens, rather than accentuates, the lumbar lordosis.

Several explanations for this are possible but are beyond the immediate scope of this discussion. The importance of Toppenberg and Bullock's finding lies in the demonstration of a relationship between quantitative indices of the lumbar curve and quantitative indices of hamstring length. This introduces the possibility of using such indices in ergonomics to investigate mechanisms of postural adaptation to seats and provides a framework for quantitative investigations of the work of Keegan (1953).

Measurements of muscle length do not appear to have been used in ergonomics research to test hypotheses about posture or to investigate workspace design. They are more commonly used in clinical assessment and research (e.g. Beiring-Sorensen, 1984, Pope et al., 1985, Toppenberg and Bullock, 1986). A brief review of some basic concepts of muscle length and its measurement is therefore appropriate.

Following Grieve and Pheasant (1982), the discussion may begin with muscle length and muscle contraction. A muscle may be removed from the body and placed in an apparatus suitable for manipulating its length and for determining the tension required to maintain the muscle at a given length. The procedure enables a passive length-tension curve to be plotted and demonstrates that the muscle has a resting length (or range of lengths) requiring minimum tension for its maintenance. To maintain the muscle at lengths greater than the resting length requires tension to overcome the elastic resistance of the muscle. This tension has to be sharply increased to further increase the muscle length.

If the same muscle is now electrically stimulated, contraction takes place. Contraction is a physiological state which gives rise to tension in the muscle. If no opposing forces are present or if they are less than the tension produced, then the muscle shortens. This is known as a concentric contraction. If the opposing forces are equal to the tension produced, the muscle length remains constant. This is known as an isometric contraction. Finally, if the opposing forces are greater than the tension, the muscle will lengthen. This is known as an eccentric contraction. An isolated muscle may be stimulated at different lengths to provide a second length-tension curve. If the passive tension at a given length is subtracted from the total tension, an active length-tension curve may be plotted.

Gordon, Julian and Huxley (1966) investigated isometric tension in isolated frog muscle fibres in relation to sarcomere dimensions. They found a relationship between length and tension characterised by an optimum region of maximum tension bounded by regions of lesser tension. The shape of the length-tension curve, the location of the optimum region and regions of lesser tension corresponded to critical stages of overlap between thick and thin filaments. They concluded that many features of the length-tension relationship could be explained by the sliding filament theory of muscle contraction.

In the living organism, muscles form part of a larger system of bones and joints. They exert tension which is transmitted via bony attachment points and gives rise to torque around the joint (Grieve and Pheasant, 1982). The magnitude of the torque depends not only on the tension exerted by the muscle (and therefore on the muscle length) but also on the geometry of the joints and the mechancial advantage of the muscles at a particular joint angle. Angle-torque curves can be determined empirically for different joints. For example, the flexion torque exerted about the elbow joint is greatest in the middle portion of the range because the elbow flexors have a greater mechanical advantage in this position. Thus, there is a close relationship between posture, muscle length and the torque exerted around joints.

Measurements of muscle length and strength may be used in clinical evaluation of patients as part of a battery of biomechanical and other tests. Kendall et al (1967) describe tests for muscle strength which require patients to carry out standardised movements in particular postures. By observing how the activity is accomplished, the trained clinician can evaluate the strength of the muscle. Sometimes, weakness in a particular muscle can be detected even in the presence of compensatory involvement of other muscles. Muscle strength tests evaluate the ability to generate tension by observing the resulting body movements. Quantitative estimates of muscle strength can be obtained using suitable apparatus. Pope et al. (1979) included measures of trunk flexor and extensor moment in a battery of biomechanical tests for the evaluation of patients with low-back pain.

Muscle length tests evaluate the muscle in a relaxed state. A body part is moved in the line of the fibres of the opposing muscle or muscle group until resistance is detected. As a general principle it is stated that a muscle must be long enough to permit normal mobility of the joints but short enough to contribute to joint stability (Kendall et al., 1967).

The conceptual model of the hip/pelvis/spine linkage presented in Figure 3.4 is not new. Forrester-Brown (1930) emphasised the clinical importance of the tilt of the pelvis in determining the posture of the spine (and not vice versa). Postural reflexes, which exist to maintain a horizontal line of sight, induce compensatory spinal curves if the pelvis tilts either posteriorly or anteriorly.

Disturbances of muscle balance result in postural deviation. Initial weakness or tightness of a muscle may cause faulty alignment of a joint and vice versa. Cause and effect may be difficult to distinguish except where some clear precipitating factor such as paralysis or trauma is extant. It is less certain that incorrect workplace design and postural fixity can lead to postural faults, although immobilisation of muscles in a shortened position has been shown to cause structural shortening and stiffening of muscles over time (Herbert, 1988). Although workspace redesign using ergonomics is an appropriate approach to the prevention of postural faults at work, the detailed knowledge of functional anatomy possessed by the occupational physiotherapist is essential for the diagnosis and treatment of individuals and the redesign of workspaces.

Further discussion of posture - the neurological underpinnings of postural control, postural behaviour and cross-cultural variation is beyond the scope of this thesis.

Summary

The lumbar lordosis in hominids is an adaptation to erect bipedalism (Robinson, 1972). Studies of the evolutionary remodelling required for the transition to an erect bidpedal posture reveal the interdependence of the anatomical adaptations to the spine, sacrum, pelvis and hip and related musculature.

This provides a conceptual framework for investigating the effects of body position on spinal curves. First, standing can be regarded as fundamental and used as a reference position for the analysis of postural adaptation to other positions.

Only part of the erection of the trunk in Homo sapiens was achieved by hip extension, the remaining 30 degrees (approximately) depended on the extension of the lumbar spine resulting in the lumbar lordosis (Robinson, 1972). The pelvis can be seen to be in an anteriorly tilted position in standing (relatively speaking).

Clinical observation demonstrates that imbalances in the system of muscles which control the tilt of the pelvis can lead to postural faults (at the level of the spine during stance). Lumbar hyperlordosis and the "flat-back" syndrome are examples of this. Toppenberg and Bullock (1990) refer to the "pelvic-crossed" syndrome in which strong erectores spinae and iliopsoas muscles are associated with weak abdominal and gluteal muscles.

When the hips and knees are flexed or extended the resting lengths of the pelvic muscles are changed. This alters the magnitude of the forces they exert on the pelvis. Thus, postural adaptation to different working positions can be hypothesised to have analogous effects on the pelvis and spine, i.e. it causes functional, but reversible, imbalances in the pelvic musculature analogous to those caused by pathology. The resulting imbalances cause a new equilibrium position and range of movement.

Thus, investigation of body positions, other than standing, should consider the spine as part of a larger system ("spine/pelvis/hip" and related musculature). Methods for doing this have been developed in the area of clinical functional anatomy. In particular, it appears that a quantitative approach to the functional anatomy of the spine can be applied in ergonomics and used to test hypotheses about the effects of body position on spinal and pelvic posture and the mechanisms of postural adaptation.

4. SUBJECTS AND METHODS

Subjects

149 subjects, 74 males and 75 females, participated in the research, partitioned across four experiments. All subjects were volunteers.

To minimise uncontrolled variation due to differences in population anthropometrics and cultural factors, all subjects were of European descent and were university students or employees between 18 and 32 years of age. Obese subjects and those with a history of musculoskeletal or spinal disease or abnormality were excluded. All subjects were free from backpain. The generality of the findings of the experiments which follow is therefore confined accordingly.

The population selected for study was limited to healthy young adults, either university students or employees. This approach has advantages and disadvantages. Subjects were freely available and could be sampled from a large pool of thousands of individuals. The subjects were likely to be free of conditions affecting the spine such as intervertebral disc degeneration - this would minimise variation in the measurements due to such factors and ensure that differences between individuals were due to natural variation in the population under study rather than pathological or age-related conditions. For example, Troup et al. (1968) observed that lumbar mobility decreased with age in males and included subjects up to 39 years of age in their study. In the present investigation, no subjects over the age of 32 years were included since it is generally held that disc degeneration commences after 30 years of age.

Physical activity is another factor which may introduce variability into a sample over and above that which would otherwise occur. For example, stretching activities as carried out in ballet, gymnastics or yoga might influence muscle length, spinal mobility or posture. Thus, participation in sports was a consideration in subject selection. In their investigation of the sagittal mobility of the lumbar spine and hips, Troup et al. (1968) selected physical education students or student teachers regularly engaging in sports and athletics. Toppenberg and Bullock (1986) in their investigation of the interrelation of spinal curves, pelvic tilt and muscle lengths, excluded potential subjects who participated in rigorous training or stretching programmes.

Participation in sporting activities is known to be high amongst young South African adults. It would not have been possible to exclude all subjects participating in regular sporting activities since this would have biased the sample in favour of physically inactive individuals.

However, it would have been possible to exclude subjects engaging in activities which involve stretching - such as ballet, gymnastics, yoga or karate - but this would not have been entirely satisfactory for a number of reasons. Firstly, many other sporting activities, although they do not demand a great deal of stretching in themselves, are practiced in conjunction with a stretching regime (e.g. running). Secondly, cause and effect may be difficult to disentangle. Subjects who participate in sports which require stretching may do so due to bodily factors conducive to the successful performance of such sports - such as muscle length. Exclusion of such subjects may reduce the range of observed values in the sample and therefore introduce a kind of type-II error due to range compression.

In correlational studies a type-II error - the conclusion that no relationship between two variables exists when in fact there is a relationship - may occur if the sampling range of one or both variables is small in relation to the degree of relationship between them. For example, if in a study of the relationship between body height and body weight, the heights of a sample of males weighing between 65 and 75 kg are correlated with body weight it is unlikely that a correlation coefficient will be statistically significant. Note that this does not depend on the accuracy or validity of the instruments used to measure the variables, it depends on the total error variance due to all uncontrolled factors. Troup et al. (1968) investigated the effects of age on lumbar movement in males and females. Lumbar mobility correlated negatively with age in males but not in females. They attributed the difference in the findings to range effects - the age range of the females was 5 years (youngest 18 years and oldest 23 years) whereas in males the age range was 21 years (18 years to 39 years).

In the present investigation a compromise position was adopted. It aimed to measure a wide range of individuals in terms of spinal posture and muscle length and, at the same time, to avoid introducing artifacts due to the inclusion of atypical individuals or groups. For this reason, professional or competitive dancers, gymnasts, or weightlifters were excluded but not subjects who engaged in these activities on a recreational basis - they were accepted as being representative of the normal population of healthy young adults. Aproximately 80% of the subjects engaged in more than one sporting activity on a regular basis - frequently the activities had different physical requirements such as gym and running, swimming and squash, cycling and hockey.

Generally the approach aimed to ensure that a heterogenous group of physically active young adults was obtained and that the samples were not dominated by particular sporting activities such as long distance running or gym.

Methods

A qualified physiotherapist/clinical tutor at the School of Physiotherapy, University of Cape Town Medical School and Groote Schuur Hospital assisted with aspects of measurement requiring specialised expertise.

All measurements were made with subjects adopting an upright, but relaxed posture in each body position measured, except where otherwise stated. Subjects were instructed to look directly ahead, fixating on a previously demarcated part of the wall in front of them. The experimenters noted the position of the head, shoulders and hip joint before taking the measurements. Occassionally, when the subjects appeared to be unstable, were slumping or stated that they were uncomfortable, the experimenters encouraged them to flex and extend the trunk a number of times (to "rock" backwards and forwards). This appeared to facilitate the adoption of a relaxed, upright posture.

Part of the investigation of the effects of body position on spinal and pelvic posture involved the measurement of spinal angles with the pelvis in relaxed, anterior and posterior tilted postures. Although data exist on the reliability of measures of lumbar angle and pelvic tilt, less information is available on measurements of pelvic ranges of motion. Gajdosik et al. (1985) investigated intratester reliability of measuring pelvic tilt in relaxed, anterior and posterior positions. They reported that pelvic tilt could be reliably measured in these three postures. However, some subjects required instruction before they were able to tilt the pelvis and hold it at the end of the range of motion for measurement.

For this reason, the reliability of measures of pelvic tilt in relaxed, posterior and anterior positions was evaluated.

Additionally, only upright, unsupported sitting postures were investigated in the first part of the research. The presence of a backrest may have obstructed free movement of the pelvis in the posterior tilted position.

Bendix and Beiring-Sorensen (1983) and Bridger (1988) observed that spinal angles do not change systematically over periods of half an hour to an hour of sitting and therefore initial measurements are likely to be valid for comparative purposes, as indices of a difference in the requirements for bodily adaptation to a particular position. Long-term measurements were not taken for this reason.

All variables were measured non-invasively. Marks were made on the skin overlying bony landmarks on the skeleton. A qualified physiotherapist/clinical tutor at the School of Physiotherapy, University of Cape Town Medical School located the bony landmarks by palpation of the skin and highlighted their position with a skin pencil. Changes in body position can cause movement of the skin over the skeleton such that a mark on the skin no longer corresponds to its bony landmark. For this reason, the marks on the skin were only used to facilitate initial placement of the measuring instruments. Final positioning of the measuring instruments was accomplished by repalpation of the underlying structures.

Measurement of Spinal Curves

An angular method of measuring spinal curvature (hereafter "spinal angles") was used, based on the method described in Loebl (1967). An inclinometer was placed on the T1-T2, T12-L1 and L5-S1 interspaces. The skin overlying the vertebrae at these positions was marked prior to measurement with the subject lying face-down. The vertically hanging inclinometer needle thus indicated the inclination of the spine at these positions enabling angular indices of lumbar and thoracic curves to be calculated, as described in Toppenberg and Bullock (1986) and depicted in Figure 4.1. All measurements of spinal angles were made by the physiotherapist.

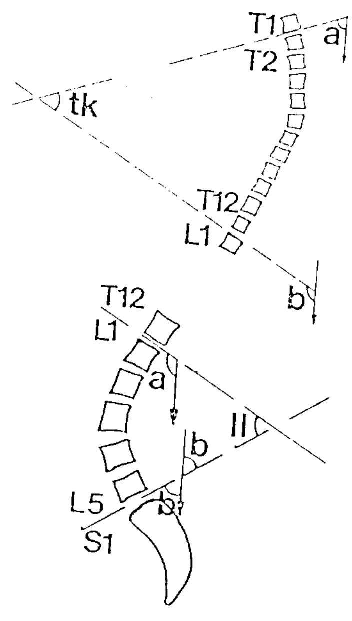


Figure 4.1 Method for the calculation of spinal angles from measured angles of inclination at T1/T2, T12/L1, and L5/S1 (adapted from Toppenberg and Bullock, 1986). Angle of thoracic kyphosis (tk): tk = 180 - a - (180 - b) = b - a. Angle of lumbar lordosis (ll): ll = 180 - (180 - a) - b = a - b.

Surface spinal inclinometry has been shown to be a reproducible method of measuring spinal angles.

Several methods of assessing spinal posture using measurements of back shape have been reported in the literature. Burdett et al. (1986) evaluated the reliability and validity of standard goniometry, tape measurement and contour measurement. Although all of the methods had advantages and disadvantages, none was found to be clearly superior to the others. Lumbar posture was more reliably measured during stance and flexion than during extension. The authors found that none of the methods correlated highly with angular measures of lumbar angle and pelvic tilt taken from radiographs. They suggested that this lack of validity might be attributable to the method they used for the external measurement of lumbar angles and pelvic tilts - they placed the inclinometer on the posterior surface of the sacrum to measure pelvic tilt and to obtain the angle of inclination of the lower part of the lumbar curve which is used to calculate the lumbar angle in the manner described in Figure 4.1. They suggested that high variability amongst the subjects between the tangent of the posterior surface of the sacrum (used in the inclinometric calculation) and the angle of the surface of S1 (used in the radiographic calculation) was the reason for the apparent lack of validity of the surface indices of spinal curvature.

For this reason, the L5-S1 interspace was used in the following experiments to obtain the angle of inclination of the lower part of the lumbar curve to calculate the lumbar angle. The L5-S1 interspace was also used as an index of pelvic tilt - specifically lumbosacral ("sacral") tilt in some of the analyses.

Measurements of Spinal Mobility

Lumbar Flexion: A version of the Schober test was used to obtain an index of lumbar flexion. Subjects bent forward as if to touch their toes, flexing the spine fully. The lumbar angle was measured using the method used in the measurement of standing lumbar angle. The difference between the two measures was taken as the range of lumbar flexion.

Lumbar Extension: Subjects lay prone on a table and extended their lumbar spines using their arms to support the weight of the trunk and head. Care was taken that the pelvis remained in contact with the table. The lumbar angle was measured and range of lumbar extension was obtained as described above.

Measurement of Pelvic Tilt

The method described in Walker et al. (1987) was used (Figure 4.2). Marks were made on the skin overlying the right anterior and posterior superior iliac spines (ASIS and PSIS) such that a calliper might be placed across them. Pelvic tilt in the sagittal plane was defined as the angle of the perpendicular to the line between the ASIS and PSIS and the horizontal. If the line between the ASIS and PSIS was parallel to the floor, a pelvic tilt angle of 90 degrees was indicated by an inclinometer attached to the calliper.

Other authors have also used the angle of a line between the ASIS and PSIS as a reference to indicate sagittal pelvic tilt. Gajdosik et al. (1985) measured intratester reliability of measuring the standing pelvic tilt and pelvic range of motion (from active anterior and posterior pelvic tilting in standing) and found their method to be reliable. Alviso et al. (1988) also found good intratester reliability using these landmarks. However, the method used by these researchers to obtain the angle of inclination of the line between the ASIS and PSIS and the reference differs from that used here.

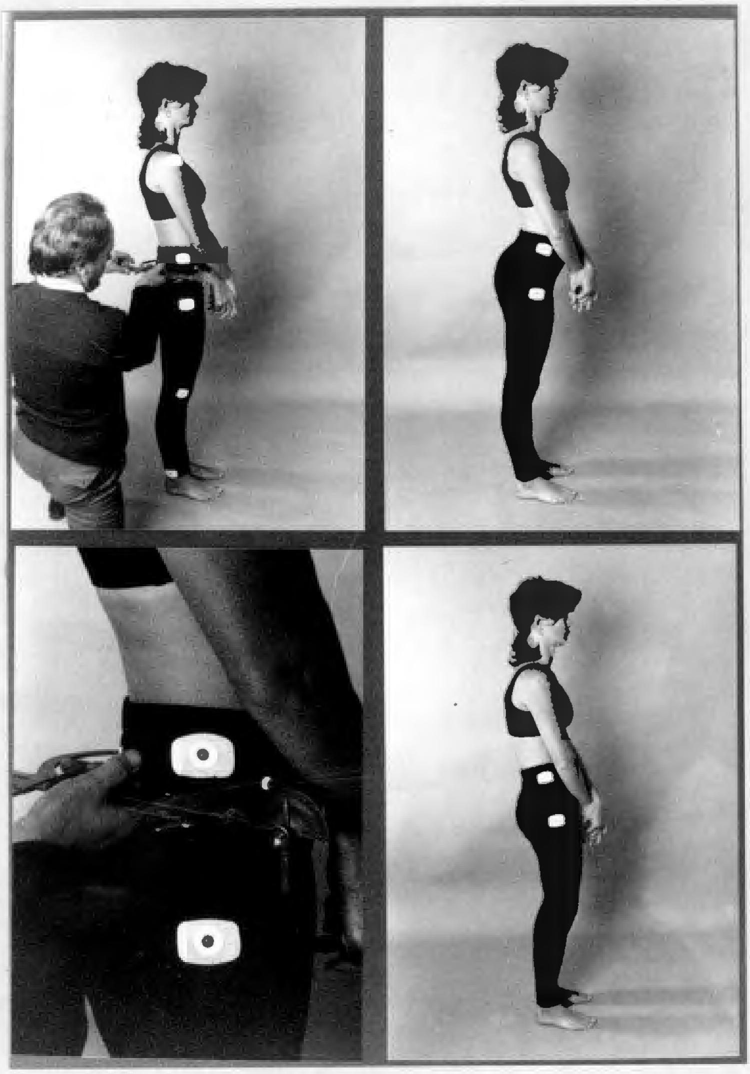


Figure 4.2 Illustration of pelvic tilt measurements using calliper with attached inclinometer. The subject executes maximum voluntary anterior and posterior pelvic tilts to enable pelvic range of motion to be measured. (Author demonstrates the method used with the assistance of a model.)

These researchers took three linear measures (the ASIS to PSIS distance and the heights of the ASIS and PSIS above the floor) and used trigonometry to calculate the pelvic tilt. This method would seem to be unduly time consuming and prone to error if not performed carefully since three linear measures are required to calculate one angular measure which can be measured directly using the same anatomical landmarks. Any inaccuracies in taking the three linear measures would be carried through in the calculation of the single angular measure. Measurements were made by the author with the assistance of the physiotherapist.

Measurement of Muscle Length

For research purposes, quantitative measures of muscle length may be obtained. In the present work, the lengths of two muscle groups were measured, the hamstrings and the iliopsoas (an attempt to measure rectus femoris length proved unsuccessful). Measures of the length of these muscles are indirect and are termed the Hamstring Index and the Iliopsoas Index. To obtain these indices, the lower limb is moved in a direction which lengthens the muscle in question. A point is reached where the muscle passively resists further lengthening. When this is detected, the angle subtended by the arc described by a predetermined point on the limb is recorded. Methods of obtaining these measures and some practical problems and precautions are described below.

Hamstring Index

Several authors describe methods of obtaining an index of hamstring muscle length (e.g. Troup et al., 1968, Fisk, 1979, Beiring-Sorensen, 1984, Pope et al., 1985 and Toppenberg and Bullock, 1986, 1990). The common principle of the methods is that subjects lie supine on a suitable table. One leg is raised by an experimenter, keeping the knee extended. This flexes the hip and lengthens the hamstrings. A point is reached where the hamstrings resist further lengthening. Attempts to raise the leg further cause physical signs such as lifting of the contralateral thigh, backward rotation of the pelvis or flexion of the knee. Subjects may also report discomfort behind the knee. Two very important points are that the pelvis is stabilised throughout the measurements and that the hamstrings are lengthened passively. If the pelvis is not stable, posterior pelvic rotation may contribute to straight leg raising and invalidate the index of hamstring length. If the subject is not relaxed, resistance may occur due to reflex activity in the muscle rather than passive stretching. Fisk (1979) suggests that subjects are able to suppress such reflex activity and that the rate of stretch should be slow (the leg must be raised slowly and smoothly).

Troup et al (1968) obtained an index of hamstring length in this way. The measured leg was raised until either the contralateral thigh began to lift or the subjects indicated the onset of discomfort. The angle between the femora was recorded using a protractor aligned to the axis through the hip joints. Using repeated observations over a period of three weeks, the reliability of the method was investigated. Correlation coefficients of 0.85 and 0.84 were obtained for the left and right sides. A potential source of error in this technique arises out of inaccuracy in locating the axis of the hip joints.

Fisk (1979a) designed a goniometer for measuring hamstring length. The centre screw of the goniometer was placed at the tip of the greater trochanter of the measured leg. The arm of the goniometer was positioned below the lateral maleolus. The subject's leg was raised until pelvic rotation was sensed by palpation of the contralateral anterior superior iliac spine and held in this position while the arm of the goniometer was raised and repositioned in relation to the lateral maleolus. The angle of the goniometer arm in relation to the horizontal was recorded.

Fisk (1979b) compared clinical estimates of hamstring length with estimates obtained using a spring gauge. Apparatus was designed to enable the leg to be raised by a cable attached to the gauge which enabled tension to be measured at different leg angles. A marked increase in tension was found to occur before the clinically determined end point (rotation of the pelvis) but the difference appeared to be small. The increase in tension was attributed to increased resistance to movement which occurs when the hamstrings cease to lengthen and other structures begin to move. This demonstrates the objective nature of the increase in tension which is used in the measurement of hamstring length. The onset of discomfort was found to coincide with the increase in tension.

Pope et al. (1979, 1985) used a photographic method to obtain an index of hamstring length. Reflective markers were placed over the lateral shaft of the femur, the tibia, and across the pelvis at the iliac crest. An initial photograph was taken with the subject resting and the leg was then elevated. A further photograph was taken when the pelvis began to move. The arc described by the movement of the reflective markers was plotted and yielded an angular index of hamstring length (see Pope et al., 1979 for a sample photograph).

Toppenberg and Bullock (1986) used a goniometer to obtain an index of hamstring length. The goniometer was strapped onto the leg with its 0-180 degree axis along a ribbon taped to the leg to indicate the line of the fibula. A reading was taken in the starting position and the leg was then raised passively with the knee extended until the knee began to flex or backward movement of the pelvis was detected by palpation. A second reading was then taken. The difference between the two readings gave the angle of hip flexion which was used as the index of hamstring length. This method appears to yield highly reproducible data.

The author knows of no research which has systematically compared each of the above methods in terms of reliability and validity. The methods appear to share many characteristics and similar precautions apply irrespective of which method is used (as described above).

In the present research, an inclinometer was used to obtain the hamstring index. With the subject lying supine on a padded table, marks were made on the skin on the medial side of the joint line of the knee. The inclinometer was placed on the resting leg in line with the marks, a reading was taken, and the leg was raised with the contralateral leg stabilised. A second reading was noted at the onset of sudden resistance or movement of the pelvis. Subjects were encouraged to indicate the onset of discomfort. The difference in readings yielded the index of hamstring length.

Iliopsoas Index

Toppenberg and Bullock (1986) obtained an index of iliopsoas length by measuring the angle of the extended thigh with the horizontal. Subjects lay supine with the legs hanging over the end of the table (so that the surface of the table did not impede movement of the thigh). With the measured thigh in a horizontal position, a goniometer positioned along the line of the femur read 90 degrees. The opposite hip was flexed to stlabilise the pelvis. The hip was then passively extended further until resistance was encountered. A second goniometer reading was taken. The difference between this and 90 degrees gave the index of iliopsoas length.

In measuring iliopsoas length it is important to ensure that the downward movement of the measured thigh is accomplished by hip extension and not by pelvic rotation and/or lumbar extension. In the present investigation the method of measuring iliopsoas length was as described below.

The subject lay supine on the table with both legs hanging over the edge. Both hips and knees were then flexed simultaneously (i.e. the subject was instructed to raise the knees to the chest). This rotated the pelvis posteriorly and flattened the lumbar lordosis (as was evident by palpation and by the fact that further movement of the knees towards the chest causes the buttocks to lift off the table and the lumber spine to flex. This provides visual confirmation that the lumbar lordosis is flattened). The subject then held one leg to the chest with the hip and knee flexed to stabilise the pelvis and the experimenter then lowered the measured leg. An inclinometer was used to position the thigh horizontal. It was placed along the estimated line of the femur and adjusted to read zero. The measured leg was then passively lowered below the horizontal and a second reading was taken when resistance was encountered. Thus, the angle to the horizontal of the arc described by the movement of the thigh was obtained and used as the index of iliopsoas length.

All measurements of muscle length were made by the physiotherapist. The author assisted by recording the measurements and checking visually for any of the physical signs described above.

Reliability of Methods

Although previous research has indicated that the methods described for measuring spinal and pelvic postures are reliable and valid, a reliability trial was carried out using five male and five female subjects.

Additionally, the test-retest reliabilities of the muscle length measures were investigated since little data on the reliability of these measurements could be found in the literature. It is known, however that circadian variation in body flexibility exists (Gifford, 1987). Maximum stiffness occurs between midnight and approximately 6:00 am. The circadian function presents a relatively flat region of maximum flexibility between midday and approximately 10:00pm. All measurements in this and subsequent work were taken in this period to minimise variation due to circadian factors. Gifford presents some data (taken from repeated measurements, by the same person, of one subject over two weeks) to suggest that the straight-leg raising test is reliable. A correlation greater than 0.90 ($p<0.01$) was reported by Gifford for the intra-observer reliability of the test.

<u>Procedure</u>

Spinal angles, pelvic tilts and muscle lengths were measured. Each measurement was repeated 5 times per subject, the subject returning to the starting position each time. The intra-observer reliability was not required. The physiotherapist located the bony landmarks and measured the muscle lengths and spinal angles in this and all subsequent experiments.

The muscle lengths were measured first. The spinal angles and

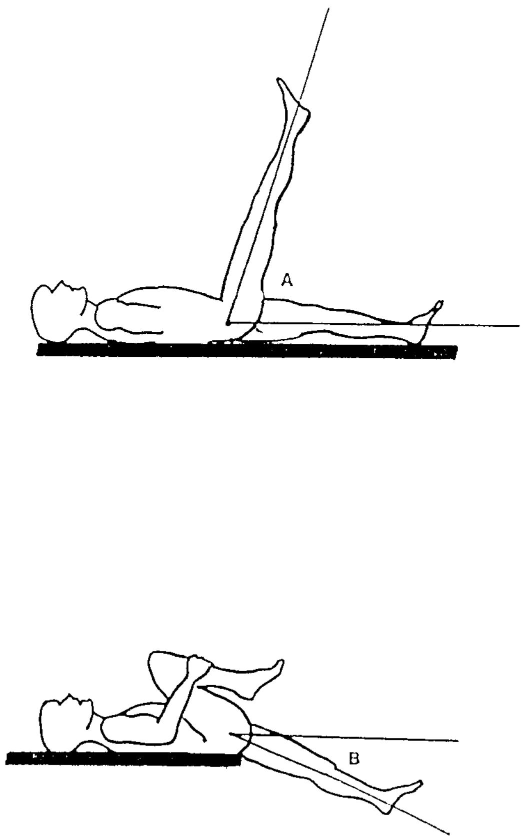


Figure 4.3 Muscle length length

(a) Hamstring Index

(b) Iliopsoas Index

pelvic tilts were measured simultaneously - one experimenter measuring the spinal angles and the other the pelvic tilts. Means and standard deviations of subject age, height and weight are given in Table 4.1.

TABLE 4.1

Means and Standard Deviations of Subject Age, Height and Weight (N=5)

	Males		Females	
	$\overline{x}$	s	$\overline{x}$	s
Age (yrs)	23.6	2.0	24.4	4.6
Height (cm)	175.0	4.6	164.0	6.9
Weight (kg)	72.8	5.6	58.7	2.6

Results

The data were analysed using ANOVA. The total sum of squares was partitioned into between and within-subjects components. The within-subjects component may be taken as the estimate of the measurement variance (Healy and Osborne, 1981) which may be used to evaluate the error due to the method. The square root of the measurement variance (Wss) is the standard deviation of the method and the proportion of the total variance (Tss) which is due to measurement variance can be used to calculate the reliability of the method (i.e. R = 1 - Wss/Tss).

Table 4.2 presents the results of the analyses for each of the postural variables. The hip flexion and pelvic tilt measures are the most reliable while the measures of spinal angles are apparently the least reliable probably because they are compound measures from two bony landmarks and because the total sums of squares in the analyses of these measures were small with respect to the sums of squares due to error.

TABLE 4.2

Reliabilities and Standard Deviations (in degrees) of the methods (N=5)

	Males		Females	
Muscle Lengths	r	s	r	s
Hamstring Index	0.98	2.2	0.99	1.8
Iliopsoas Index	0.95	1.8	0.89	4.0
Spinal Angles				
Thoracic Angle	0.89	3.0	0.79	2.5
Lumbar Angle	0.77	3.1	0.90	2.9
Pelvic Tilt				
Sacral Tilt	0.86	2.6	0.91	2.6
Neutral	0.89	0.8	0.96	1.0
Anterior	0.92	2.3	0.95	1.7
Posterior	0.92	1.9	0.88	2.0

Discussion

A number of the methods of measurement appear to lack reliability according to the previous analysis. Apart from technical sources of error such as the ability to reliably identify bony landmarks, or the ability of subjects to remain still during measurement, a statistical explanation is also possible. When reliability is expressed in terms of measurement variance as a percentage of total variance, a method can appear unreliable if the total variance in the sample is small. This can occur, particularly with small samples if all the subjects are of a similar body type or carry out similar yet atypical activities (i.e. if the sample is homogeneous). These considerations were included in the selection of subjects, as described previously.

Validity of the Measures

The reliability of a method of measurement refers to the reproducibility of the results it yields when used under the conditions for which it was designed. Validity, however, depends upon the extent to which a method measures what it is designed to measure. A method may be reliable but not valid. However, an unreliable method is unlikely to be valid.

Spinal Angles

A number of researchers have investigated non-invasive methods of characterising the shape of the spine. Bryant et al. (1989) used curve fitting techniques to transform a skin profile to a vertebral centroid curve using data from lateral radiographs. The technique enables vertebral centroid positions to be estimated from skin profile data to an accuracy of up to 0.2 cm. This technique was judged to be somewhat advanced for present purposes since only global indices of lumbar and thoracic angles were required.

When investigating the validity of non-invasive measures of spinal curvature, a correlational approach is often used - non-invasive measures from a number of subjects are correlated with measures taken from radiographs of the same individuals. The size of the correlation coefficient is often used to decide upon the validity of the non-invasive method. However, as Adams et al. (1986) point out, radiographs are sometimes difficult to interpret and can contain distortion. The difference between the non-invasive and the radiographic method is due to the combined error of the two, not solely the error due to the non-invasive method.

The inclinometric method of obtaining indices of spinal curvature has been evaluated by several researchers. In the investigation of the lumbar spine, the angle obtained is a non-invasive version of the Cobb angle - a common method of assessing spinal curvature from radiographs. The validity of Cobb's method has been questioned because it only considers the end vertebrae of a curve and ignores those intervening. Voutsinas and McEwan (1986) compared Cobb's method with an alternative which provided an index based on the length and depth of spinal curves. They found that Cobb's method compared favourably with the alternative in normal spines but questioned its use in the diagnosis of pathological conditions. Numerous studies have been carried out to determine the validity (with respect to radiographs) of measurements of back-shape as indices of spinal curvature. Troup et al. (1968) found a high correlation (0.91) between photographic and radiographic methods. Wilner (1981) developed a spinal pantograph and found its measures of the thoracic curve to correlate well with those from radiographs. Less agreement between the pantograph and radiographs in lumbar assessment was attributed to inaccuracy in the radiographic method because the lower border of the lordotic angle is not well defined.

The inclinometric method used here describes back shapes rather than spinal curves. This does not present problems if the back shape depends mainly on the spinal curve and the effects of other variables (e.g. skin thickness, back muscles) are small. Surface spinal inclinometry has been shown to be a reproducible method of measuring spinal angles which correlates well with angular measures taken from radiographs (Adams et al., 1986) except when measuring older subjects in positions of extreme extension, where skin wrinkling prevents accurate placement of the inclinometer.

<u>Pelvic Tilt</u>

Measurement of pelvic tilt is more straightforward than that of the other variables since the bony landmarks are well-defined and the tilt may be measured directly.

Muscle Lengths

The question of validity in relation to the measurement of muscle lengths can be addressed in at least two ways. Firstly, for the measure to be valid, it must be the muscle being measured that is limiting movement of a body part (in this case the thigh) and not the joint or some other muscle. In the straight leg raising procedure, the hamstrings limit further raising of the leg. If the knee is flexed, the insertion of the hamstrings is brought closer to the origin and further hip flexion is possible. This can be seen in the measurement of the iliopsoas index when the opposite thigh is raised to the chest (Figure 4.3b).

A second consideration is that the muscle limits movement due to passive rather than active processes (such as an eccentric contraction). According to Fisk (1979), the resistance to leg raising is due to a gradual stretching of the skin and subcutaneous tissues and the inherent resistance of the muscles to lengthening. The sudden increase in resistance is due to the coupling of the pelvis and lumbar spine which occurs when the hamstrings cease to lengthen further. This can also occur if reflex contraction takes place and would lead to an underestimate of the muscle length. According to Fisk, subjects are able to consciously suppress such activity particularly if the required movements are carried out slowly. In the present research, an experienced physiotherapist carried out the tests in an effort to ensure that error from these sources was avoided.

There appears to be a lack of standardised terminology for many of the measurements described here. Since all of the measurements are made externally, it can be argued that a "black box" approach is appropriate in describing them. For example, Troup et al. (1968) and Pope et al. (1986) refer to the "straight leg raising test" used to detect hamstring tightness. Other researchers look to the underlying structures. For example, Fisk (1979) refers to the "passive hamstring stretch test" whereas Toppenberg and Bullock (1990) refer to the "hamstring length index". Despite the differences in terminology used by different researchers, their interpretation of this type of data is essentially the same.

Measurements of "muscle Length" involve movement of a body segment in the opposite direction to the muscle being measured. Resistance to movement is attributed to passive stretch of the muscle. The measures are therefore externally made measures of joint movement in a prescribed position. The muscle itself is not directly observed nor is its length measured in any sense.

The terms "Hamstring Index" and "Iliopsoas Index" are used in the present research, even though the measures involve flexion and extension of the hip joint. These terms are economical and serve to distinguish the measurements from other, quite different, measures of hip mobility (e.g. Clayson et al, 1962, Ahlback and Lindahl, 1964).

The terms "Lumbar Angle" and "Thoracic Angle" are used to describe the indices of spinal curvature obtained using the inclinometers. Some researchers (e.g. Adams et al., 1986) refer to the lumbar measure as a measure of lumbar curvature. This is not strictly true since the method yields an angle, not a curve. The magnitude of the angle depends on the back shape, which in turn, depends on the curvature of the spine (Bryant et al., 1989).

The terms "Lumbar Flexion" and "Lumbar Extension" are used to describe the angle obtained when the lumbar spine is fully flexed or fully extended. "Pelvic Angle" refers to the angle of pelvic tilt measured using an inclinometer.

5. EXPERIMENT 1: The Effects of Seat Slope and Hip Flexion on Spinal Angles

Introduction

25 male and 25 female subjects participated in the experiment (Table 5.1). The spinal angles of the subjects were measured in standing and in four different sitting postures described below. The purpose of the experiment was to test the hypothesis that spinal posture is determined by body position and to estimate the magnitude of any effects.

According to the view derived from Keegan, body positions which differ in the amount of hip flexion (but with equal knee flexion and trunk position) should give rise to different spinal postures for the reasons discussed previously. Several authors (e.g. Mandal, 1981) have based their arguments for the use of forward sloping seats on this view.

However, the study of hominid evolution suggest that the pelvis is tilted forwards in standing with the ischium posterior to the hip joint to make way for the trailing leg during walking. Both Homo sapiens and chimpanzees sit on the ischial tuberosities (Hewes, 1957) and, in the former, posterior pelvic rotation will always be part of the postural adaptation to sitting. According to the view derived from Branton (1969), a forward sloping seat should cause the pelvis to rock forwards over the ischia and thus increase the lumbar angle as compared to a flat seat even if hip flexion is the same on both seats.

The experiment was designed to determine which of these two factors (hip flexion and seat slope) have statistically significant effects on spinal posture and, if both have significant effects, to determine whether they are independent factors or whether they interact.

It was hoped that the findings of the experiment would clarify the usefulness of different options for seat design.

Method

A repeated-measures design was used with three factors: seat slope, hip flexion and sex of subjects. Each subject sat in four positions (Figure 5.1) in random order:

1. Sitting with a 90-degree trunk-thigh angle on a horizontal seat.

2. Sitting with a 65-degree thigh angle on a horizontal seat (to simulate sitting "perched" on a stool or on a sloping seat with a horizontal ischial support).

3. Sitting with a 90-degree thigh angle on a seat with a 15-degree forward slope (to determine the effect of seat slope on posture).

4. Sitting with a 65-degree thigh angle on a seat with a 15-degree forward slope.

Standing was used as a reference posture throughout.

Knee flexion was kept as close to 90-degrees as possible in each position. In the 65-degree positions, a kneepad was used to stabilise the subjects. Trunk-thigh angles were set manually by the experimenters using an inclinometer to position the thighs. The inclinometer was placed on a line from the lateral condyle to the greater trochanter of the femur.

To assist in positioning the trunk, the method of Bridger et al. (1989) was used in addition to the general precautions described in the methods section. A "balanced" erect position was obtained in all positions. Electrodes were placed on the skin over the rectus abdominis and erectores spinae muscles. Electromyographic (EMG) activity was amplified and displayed. The displayed signals were used as feedback by the subjects and experimenters such that an erect sitting posture was obtained when EMG activity in both channels was simultaneously minimal, the head was erect and the acromion was approximately vertically above the greater trochanter. Spinal angles were then measured.

Table 5.1

Means and Standard Deviations of Subject Age, Height and Weight (N=25)

	Males (N=25)		Females (N=25)	
	$\bar{x}$	s	$\bar{x}$	s
Age (yrs)	28.4	10.8	22.4	5.2
Height (cm)	178.5	6.6	169.3	8.1
Weight (kg)	73.9	7.3	60.9	6.4

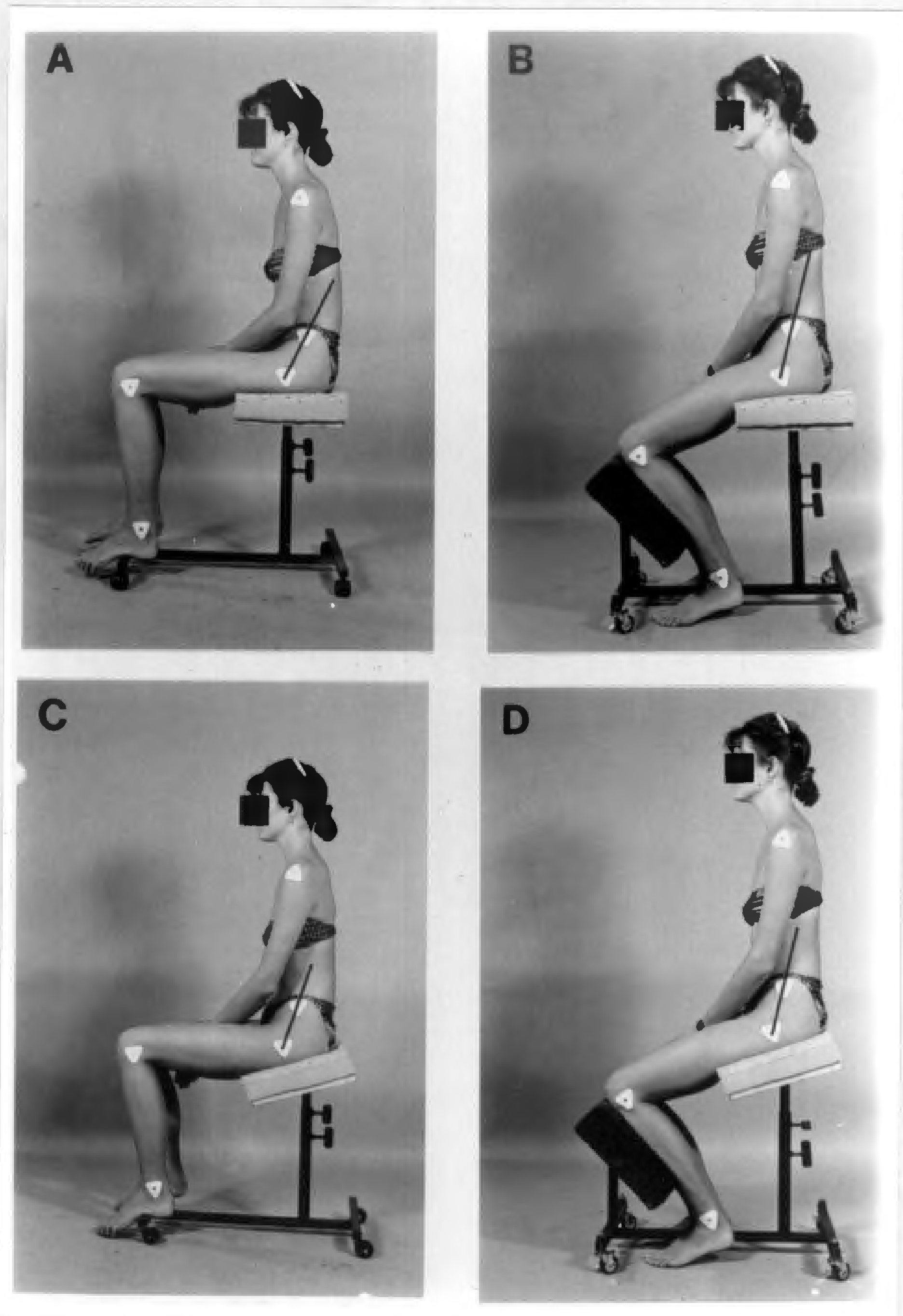


Figure 5.1 Sitting positions investigated.

Results

Spinal Angles in Standing and Sitting

Tables 5.2 and 5.3 present means and standard deviations of lumbar and thoracic angles in standing and in the four sitting positions. Four indices are presented for the lumbar angles:

1. Raw Scores (RW)
2. As a percentage of the total range of motion (RNG%)
3. Difference (or change) between angle in standing and sitting (CHN)
4. Change in angle as a percentage of total range of movement (CHN%)

Only raw and change scores are presented for the thoracic angles because, in extension, the scapular musculature contracts, preventing accurate measurement.

Lumbar angle was smallest when the 90-degree position was adopted on the horizontal seat and least when the 65-degree posture was adopted on the sloping seat. Intermediate results were obtained for the remaining conditions. Alterations of the lumbar curve were less pronounced in females than in males.

Analysis of Factors Influencing Spinal Angles in Sitting

Lumbar and thoracic angles in sitting were analysed using ANOVA to give F-Ratios for seat slope, hip flexion and subject sex as main factors, as well as the interaction terms among them. The ANOVA results are presented in Tables 5.4 and 5.5 and interpreted as follows.

Lumbar angles: Subject sex had a statistically significant effect on lumbar angle in the four sitting positions. Females had less flexion than males in all positions. Female lumbar angles tended to be closer to the midpoint of the flexion/extension range than did the males' and were closer to the lumbar angles measured in standing. Seat slope had a significant effect on lumbar angle for both males and females. Large lumbar angles were observed with the sloping seat and when the 65-degree position was adopted.

Only one of the interaction terms reached statistical significance; this may be a chance effect due to the number of interaction terms calculated.

<u>Thoracic angles:</u> No statistically significant differences in thoracic kyphosis were observed between males and females although the thoracic angle was smaller in sitting than in standing. Seat slope and hip flexion both had significant effects on thoracic angle, which was greater and closer to the standing angle under the sloping seat and/or the 65-degree sitting positions. No interaction terms reached statistical significance.

<u>Relationships Between Sacral Tilt and Lumbar Angle.</u>

Regression analyses of sacral tilt - the angle measured at L5/S1 and lumbar angle were calculated with sacral tilt as the independent variable. The data were analysed separately for males and females and for standing and each of the sitting positions. This gave 10 separate regression analyses that attempted to fit the following monotonic functions to the data:

1. $Y = A + BX$
2. $Y = Ae^{(BX)}$
3. $Y = A + B \log (X)$
4. $Y = A \times X^B$

The first model attempts to fit a straight line to the data. The remaining are commonly used curvilinear models which were chosen to detect whether a non-linear relationship existed between the variables.

TABLE 5.2

Means and Standard Deviations of Lumbar and Thoracic Angles (degrees) in Standing and in Four Sitting Positions: Males (N=25)*

			Sitting			
		Standing	1	2	3	4
Lumbar angle						
RW	$\bar{x}$	33.6	-12.3	-6.12	-8.5	-2.6
	s	10.9	11.1	10.4	9.7	9.6
RNG%	$\bar{x}$	78.8	19.8	26.5	23.6	31.9
	s	13.7	10.3	10.6	10.0	11.0
CHN	$\bar{x}$	N/A	45.9	39.8	42.1	36.2
	s		12.7	13.7	11.7	13.1
CHN%	$\bar{x}$	N/A	59.1	52.0	54.6	46.2
	s		15.5	18.6	15.8	17.2
Thoracic angle						
RW	$\bar{x}$	55.8	41.9	43.3	44.2	47.4
	s	7.9	8.6	8.7	7.2	7.9
CHN	$\bar{x}$	N/A	14.0	12.6	11.8	8.7
	s		8.6	7.3	7.0	7.0

* RW = raw scores; RNG% = percentage of total range of movement; CHN = change in lordosis or kyphosis from standing; CHN% = change as a percentage of total range of movement.

TABLE 5.3

Means and Standard Deviations of Lumbar and Thoracic Angles (degrees) in Standing and in Four Sitting Positions: Females (N=25)*

			Sitting			
		Standing	1	2	3	4
Lumbar angle						
RW	$\bar{x}$	34.8	-1.0	4.6	3.2	10.9
	s	9.9	7.8	7.5	7.6	9.2
RNG%	$\bar{x}$	65.4	24.1	30.6	28.1	37.6
	s	14.2	9.5	10.0	7.5	11.9
CHN	$\bar{x}$	N/A	35.8	30.5	29.7	24.1
	s		8.8	11.5	14.8	14.1
CHN%	$\bar{x}$	N/A	41.9	34.8	37.3	28.2
	s		14.6	15.0	16.7	19.6
Thoracic angle						
RW	$\bar{x}$	53.7	42.8	45.0	46.0	48.2
	s	7.8	6.6	7.5	5.7	7.0
CHN		N/A	11.1	9.2	8.1	5.9
			(8.1)	(6.4)	(7.1)	(5.6)

* RW = raw scores; RNG% = percentage ot total range of movement; CHN = change in lordosis or kyphosis from standing; CHN% = change as a percentage of total range of movement.

TABLE 5.4

F Ratios (and Factor Sums of Squares as a Percentage of Total Sum of Squares) from the ANOVA of the Effects of Subject Sex (A), Seat Slope (B) and Hip Flexion (C) on Lumbar Angle***.

	Lumbar Index			
Factor	RW	RNG%	CHN	CHN%
A	25.7* (26.4)	11.4* (15.2)	3.7 (4.3)	15.4* (20.8)
B	32.9* (3.8)	29.7* (3.1)	22.4* (5.0)	24.6* (2.0)
C	70.7* (7.7)	35.2* (4.1)	63.6* (11.8)	63.7* (4.3)
AxB	1.1 (0.0)	2.0 (0.2)	0.2 (0.3)	0.0 (0.0)
AxC	0.2 (0.0)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)
BxC	1.1 (0.0)	0.0 (0.0)	4.2** (0.3)	2.3 (0.0)
AxBxC	1.8 (0.0)	0.0 (0.0)	0.5 (0.0)	0.1 (0.0)

* Statistically significant p<= 0.01.
** Statistically significant p<= 0.05.

*** RW = raw scores; RNG% = percentage of total range of movement; CHN = change in lordosis or kyphosis from standing; CHN% = change as a percentage of total range of movement.

TABLE 5.5

F Ratios (and Factor Sums of Squares as a Percentage of Total Sum of Squares) from the ANOVA of the Effects of Subject Sex (A), Seat Slope (B) and Hip Flexion (C) on Thoracic Angle in Sitting**.

Factor	Thoracic Index	
	RW	CHN
A	0.5(0.8)	3.0(4.5)
B	54.5*(4.4)	55.0*(4.3)
C	13.2*(2.2)	11.1*(2.0)
AxB	0.0(0.0)	0.0(0.0)
AxC	0.0(0.0)	0.0(0.0)
BxC	0.8(0.0)	1.0(0.1)
AxBxC	0.8(0.0)	0.6(0.0)

* Statistically significant p<=0.01.

** RW = raw scores; CHN = change in lordosis or kyphosis from standing.

In all but two of the analyses, only the linear model fitted the data. Table 5.6 presents the results of the linear analyses which were statistically significant in all positions.

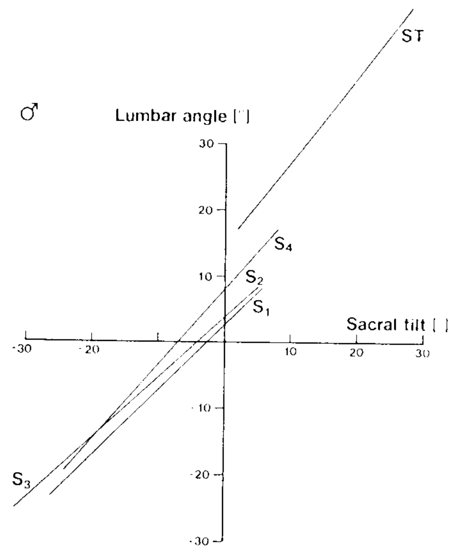
ANOVA of slope differences between postures was not statistically significant for either males or females ($F = 0.049$ and $F = 0.01$, respectively, $df = 4$ and 15, $p > 0.05$). Common slopes, calculated separately for males and females were 1.10 and 1.028 respectively. The difference between the common slopes was also not statistically significant ($t = 0.22$, $df = 6$, $p > 0.05$) and the estimate of combined common slope (males and females together, over all positions) was 1.066. Figure 5.2 depicts the findings graphically.

TABLE 5.6

Linear Regression Analyses of Sacral Tilt and Lumbar Angle (in degrees) in Standing and in Four Sitting Positions

		Y Intercept	Slope	Correlation	F Ratio*
Males					
Standing		14.2	1.3	0.92	127.0*
Sitting:	1	2.7	1.2	0.81	43.0*
	2	3.5	1.0	0.77	32.6*
	3	3.5	0.9	0.79	38.6*
	4	7.5	1.1	0.86	65.5*
Females					
Standing		20.8	0.9	0.91	109.5*
Sitting:	1	3.4	1.0	0.78	36.9*
	2	6.8	1.1	0.83	52.3*
	3	7.4	1.1	0.89	86.4*
	4	9.4	1.1	0.87	70.0*

* For 1 and 23 degrees of freedom, F-values greater than 7.88 are statistically significant ($p \leq 0.01$).



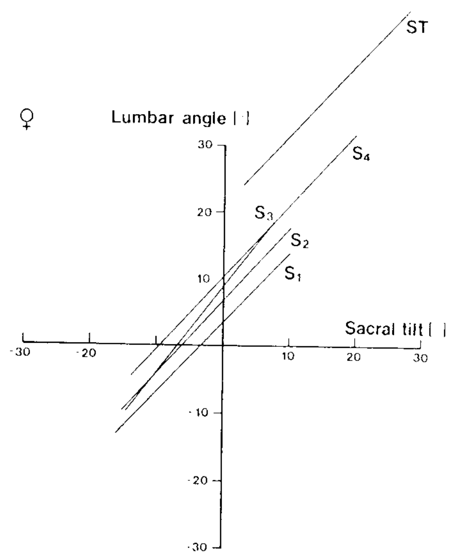


Figure 5.2 Relationships between sacral tilt and lumbar angles in standing and sitting in males (top) and females (bottom).

Discussion

The present investigation utilised a sample of young, healthy adults with no history of musculoskeletal disease. The generality of the findings is confined accordingly.

The hypothesis that seat slope and reduced hip flexion independently contribute to the preservation of the lumbar lordosis, when sitting, was corroborated. Alterations of the spinal angles observed in standing occurred in all sitting postures. This was more pronounced among male than among female subjects. In all sitting postures a method was used to position the trunk such that it was in an erect posture with no obvious compensation of the anterior and posterior muscles for a particular experimental condition.

Postural adaptation to the conditions was therefore attributable largely to the effects of hip flexion and forces at the buttock-seat interface.

Seat slope and hip flexion both had significant effects on spinal angles, particularly at the lumbar spine. Reduced hip flexion and forward slope tended to reduce lumbar flexion. The forward-sloping seat, when the subject had a 65 degree trunk-thigh angle, produced the least lumbar flexion. Only one of the interactions among the experimental factors was statistically significant. This suggests that seat slope and hip flexion act in an additive manner to reduce lumbar flexion and that this is applicable to both male and female subjects.

These findings are in general accord with those of other authors. According to the approach taken in the present investigation, the findings support a view of seating based on a consideration of the ischia as an unstable base of support, which may be influenced by postural adaptations that determine hip flexion and by forces imposed on it by the action of superincumbent body parts at the buttock-seat interface.

In the standing position there appeared to be little difference between the lumbar and thoracic angles of male and female subjects (mean lumbar angles were 33.6 and 34.8 degrees and mean thoracic angles were 55.8 and 53.7 degrees for males and females, respectively). In all sitting postures females exhibited less of a reduction in lumbar lordosis than did males. This was observed for all indices of lumbar curvature. No such differences were observed for the thoracic indices.

Several authors, however, have recently discussed the relationship between pelvic tilt and lumbar lordosis. In a radiographic investigation, Voutsinas and MacEwan (1986) found significant correlations between sacral inclination and lumbar lordosis in standing for both males and females. In childhood, girls were observed to have higher degrees of sacral inclination and pelvic tilt than boys, but by maturity these measurements were similar in both sexes. Alternatively, Walker et al. (1987), in a non-invasive investigation of relationships among lumbar lordosis, pelvic tilt, and abdominal muscle performance, concluded that no relationship appeared to exist between these variables.

The present findings suggest that there is a relationship between lumbar angle and sacral tilt and that the relationship is linear within the range of observed postures. The regression analyses of sacral tilt and lumbar angle were statistically significant. Further, considering that slope differences were not statistically significant, this relationship appears to hold irrespective of the chair used or, indeed, whether or not the subject is standing.

However, the relationship between lumbar angle, sacral tilt and pelvic tilt remains unknown and will be investigated in the next experiment.

No significant differences were observed between the slopes of regression analyses for males and females despite the fact that the reduction in lumbar lordosis was greater in males than in females, as discussed earlier. The degree of linear relationship between sacral tilt and lumbar angle does not, therefore, appear to be sex dependent. Mean standing sacral tilts were approximately 14.7 and 14.8 degrees for males and females, respectively. Changes in sacral tilt when adopting the four sitting postures varied approximately from 20 to 30 degrees for males and 10 to 20 degrees for females. This provides additional support for the view that the observed differences in postural adaptation between males and females are the result of anatomical factors external to the lumbar spine. This issue will be addressed later.

Lumbar angle may be expressed in terms of lumbar flexion/extension range. The lumbar spine in standing was 79% and 65% extended for males and females respectively. In the sitting positions, the lumbar angles ranged from 20-32% of maximum extension in males and 24-38% in females. Greater postural adaptation to the seats seems to have taken place in the spines of males than females. Whether this is due to differences in muscle length remains to be investigated.

Conclusions

The hypothesis that body position determines spinal posture was supported. Seat slope and hip flexion had statistically significant effects on lumbar angle. In cases where the sitter may not reduce hip flexion, due to space limitations for example, a forward sloping seat may still assist in reducing lumbar flexion. Alternatively, the findings suggest that the industrial stool concept of Corlett and Eklund (which has a flat region for the ischia and a sloping front to enable the thighs to point downwards) would also reduce lumbar flexion. However, the largest effects will be expected when these design features are combined since their effects are additive.

The inclinometric method appeared capable of testing the hypotheses in a meaningful way and enabled spinal angles in standing and in different sitting positions to be distinguished. Pelvic tilt and its relation to spinal and sacral angles in standing and in sitting remains to be investigated.

It is noteworthy that in none of the positions was the lumbar spine close to the mid-point of its range of movement, particularly in males. In standing, it was extended and in sitting flexed. Investigation of a greater variety of body positions would appear to be warrented to provide more information on the natural variation in lumbar posture.

6. EXPERIMENT 2: Interrelationships Between the Spine, Pelvis and Hip: measurements in standing and in different working positions.

Introduction

The purpose of this experiment was twofold. Firstly, to carry out a further test of the hypothesis that spinal and pelvic angle is determined by body position but using a greater variety of positions than in the previous experiment. Secondly, an investigation of the mechanism of postural adaptation to different body positions was carried out. This was achieved in two ways:

- By examining the range of motion of the spine and pelvis in standing and in the different body positions.
- By testing the hypothesis that change in pelvic angle is related to hamstring length in sitting. Subjects with long hamstrings were hypothesised to experience less posterior pelvic rotation in sitting than those with short hamstrings.

Standing was used as a reference posture for the reasons discussed previously. An exploratory analysis of the interrelationships between spinal and pelvic angles and muscle lengths was carried out to assist interpretation of the data.

25 male and 25 female subjects participated in the experiment. Means and standard deviations of age height and body weight are given in Table 6.1.

Method

A repeated measures design was used. Each subject was measured in the nine positions shown in Figure 6.1 The positions are described as follows:

1. Standing. This was used as a reference posture. Toppenberg and Bullock (1986) found a negative correlation between

hamstring length and lumbar lordosis in adolescent females. A similar finding was reported by Bridger et al. (1989) in a sample of adult females. An attempt to replicate this finding was made using a sample of adult males and females.

2. Low Sitting. This position simulated sitting on a low stool or bench with the legs outstretched and pointing downwards by 25 degrees. Since the knees are extended and the hamstrings are lengthened, it was hypothesised that hamstring length would be associated with postural adaptation to this position.

3. Long Sitting. Most adults in western societies find this position difficult to adopt (although it is a common working position in some societies). As in the previous position, a significant relationship between hamstring length and postural adaptation was expected.

4. Two-Point Kneeling. This position simulated working at a low worksurface (e.g. making beds, cleaning a low shelf) or praying. Since the hamstrings are not lengthened in this position, no relationship with posture was predicted.

5. Open Sitting. This posture simulated sitting on the edge of a chair with the thighs pointing downwards by approximately 25 degrees and the knees flexed by 90 degrees. This position is said to be close to the "neutral" position of the hip joint described by Keegan (1953) in which sitting is accomplished without hamstring stretch. No relationship between hamstring length and posture was predicted.

6. 90 Degree Sitting. In the conventional upright sitting posture, it is usually suggested (e.g. Mandal, 1981) that the reduction in lumbar curvature is due to passive pull of the hamstring muscles on the pelvis. An association between hamstring length and posture was predicted.

TABLE 6.1

Means and Standard Deviations of Subject Age, Height and Weight

	Males (N=25)		Females (N=25)	
	$\bar{x}$	s	$\bar{x}$	s
Age (yrs)	22.5	4.3	21.6	3.2
Height (cm)	179.3	4.4	166.6	5.9
Weight (kg)	74.7	8.0	59.1	5.6

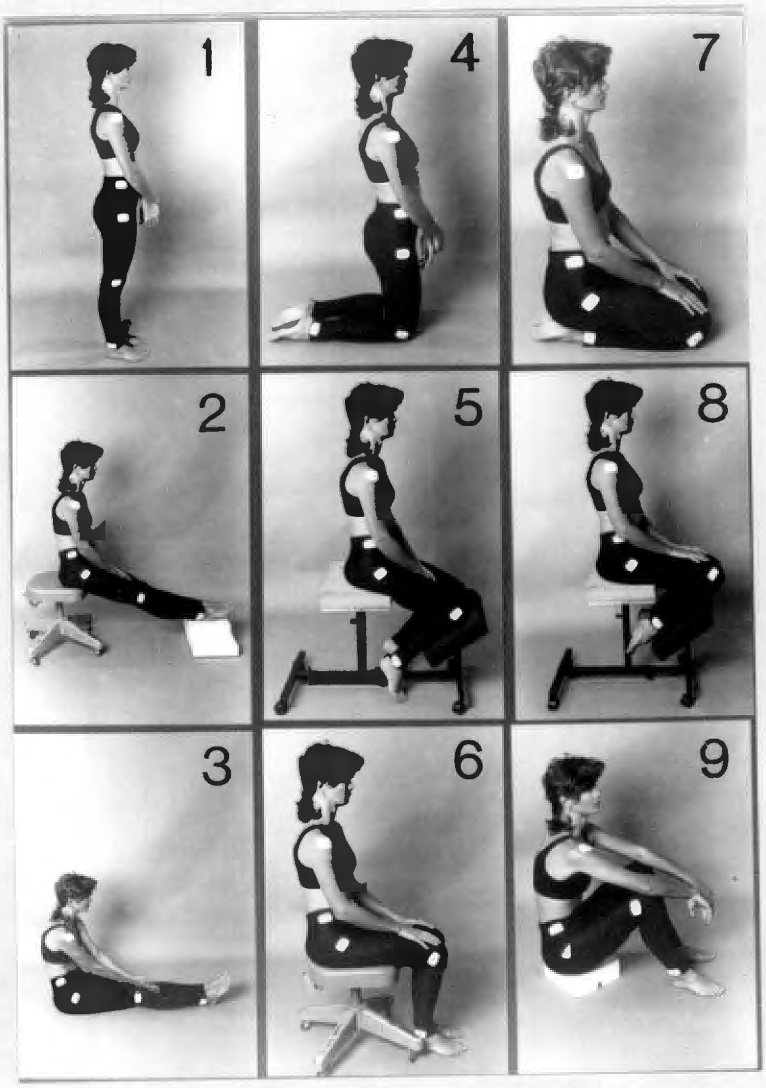


Figure 6.1 Working positions investigated in the experiment.

7. Kneeling. This posture is more common in Asia than in western societies. Neither the hip flexors or extensors are lengthened in this position since the hip is flexed by approximately 70 degrees and the knee by approximately 135 degrees. No relationship between hamstring length and posture was predicted.

8. Sitting With Kneepad. Some modern work chairs incorporate a sloping seat and kneepad. A variation on the kneeling posture described above is obtained when the seat and kneepad enable the subject to sit with approximately 135 degrees of knee flexion. The previous experiment demonstrated that seat slope and hip flexion can be treated independently as factors affecting lumbar angles. For this reason, a flat seat was used in this experiment. No relationship between hamstring length and posture was predicted.

9. Semi-Squatting. Most subjects are unable to squat in the manner observed in non-industralised parts of Africa and Asia partly because their gastrocnemius and soleus muscles do not permit sufficent dorsiflexion to position the centre of gravity of the body over the base of support described by the feet. A semi-squatting position was devised in which subjects sat on a wooden plank with approximately 120 and 135 degrees of hip and knee flexion respectively. Although the hip is greatly flexed, the knee is also flexed, thus, hamstring stretch would not be expected to be related to posture.

Procedure

After carrying out the spinal mobility and muscle length measurements described previously, the spinal and pelvic angles were measured in each of the nine positions. One experimenter (the author) made the pelvic tilt measurements and the other took the spinal measurements simultaneously. Measurements were first taken in a relaxed position with the trunk erect (shoulder joint vertically above hip joint). Next, the subject was instructed to tilt the pelvis anteriorly and then posteriorly as far as possible, but without tremor. Pelvic and spinal angles were recorded on each occasion. Thus, for each working position, values of spinal and pelvic angles were obtained with the pelvis in relaxed, anterior and posterior tilted postures. (Figure 4.2 illustrates these postures during stance).

Results and Discussion

Effects of Body Position on Spinal and Pelvic Angles

Split-plot analysis of variance were carried out on the data (neutral angles only) to test the significance of the effects of the experimental factors (subject sex, thigh angle and knee angle) on the postural variables (pelvic, lumbar and thoracic angles). Table 6.2 summarises the results of the analyses.

As can be seen, significant differences in spinal and pelvic angles were observed depending on the angle of hip and knee flexion and the sex of the subjects. Alterations of the lumbar angle were larger in males than in females. This agrees with the findings of the previous experiment.

Mechanisms of Postural Adaptation 1. Spinal and Pelvic Angles, Ranges of Motion and Neutral Positions

Tables 6.3, 6.4 and 6.5 give the mean spinal and pelvic angles of males and females in each of the nine positions and with the pelvis in relaxed ("neutral"), posterior and anterior pelvic postures.

To assist visualisation, Figure 6.2 summarises the lumbar and pelvic data.

Lumbar angles and pelvic tilts were largest in two point kneeling for both males and females. This was followed by standing, kneeling and sitting with kneepad. The largest reductions in spinal angle were observed in long sitting and semi-squatting.

TABLE 6.2

F Ratios from the Analysis (ANOVA) of the Effects of Hip and Knee Flexion on Thoracic, Lumbar and Pelvic Angles for Positions 1-6 and 7-9 respectively

Factor		Anova of Postures 1-6		
	df	Thoracic	Lumbar	Pelvic
Subject Sex	1,48	19.8*	10.8*	1.6
Hip Flexion	2,96	93.9*	427.2*	519.6*
Sex X Hip	2,96	3.4**	10.3*	11.7*
Knee Flexion	1,48	1.3	64.5*	125.2*
Sex X Knee	1,48	0.3	2.0	5.7*
Hip X Knee	2,96	0.5	6.0**	13.6*
Sex X Hip X Knee	2,96	4.0*	1.2	1.8
		Anova of Postures 7-9		
Subject Sex	1,48	17.0*	9.3*	6.2*
Hip Flexion	2,96	6.9*	156.1*	264.1*
Sex X Hip	2,96	0.4	6.8*	2.6

* statistically significant, p<0.01
** statistically significant, p<0.05

TABLE 6.3

Mean and Standard Deviation Thoracic Angles (degrees) of Males and Females in Nine Positions and with the Pelvis in Posterior (P), Neutral (N), and Anterior (A) Tilted Postures

		Males			Females		
		P	N	A	P	N	A
Position							
1.	$\bar{x}$	45.5	49.9	46.6	36.2	40.0	39.2
	s	9.0	8.3	8.8	7.5	7.1	8.9
2.	$\bar{x}$	40.0	38.3	34.5	33.1	34.4	34.4
	s	7.8	8.3	8.1	9.5	6.8	10.2
3.	$\bar{x}$	46.6	40.4	37.2	38.2	31.8	29.1
	s	8.8	8.1	10.9	10.1	8.2	8.1
4.	$\bar{x}$	50.2	51.2	45.9	37.9	40.4	38.0
	s	8.2	7.7	8.3	9.0	6.2	8.8
5.	$\bar{x}$	39.1	39.7	42.5	30.6	32.3	37.4
	s	8.9	6.5	10.5	8.7	6.3	6.4
6.	$\bar{x}$	38.2	38.0	38.6	31.2	32.5	35.0
	s	8.4	7.2	8.9	7.7	5.8	9.1
7.	$\bar{x}$	36.2	40.4	43.5	30.7	33.4	35.6
	s	8.9	9.1	11.0	7.8	8.6	8.1
8.	$\bar{x}$	38.6	41.1	42.5	32.5	32.0	35.8
	s	9.8	7.1	9.6	9.1	6.0	9.7
9.	$\bar{x}$	41.6	37.6	32.1	33.0	30.2	27.6
	s	7.9	8.2	10.7	5.5	7.6	8.9

TABLE 6.4

Mean and Standard Deviation Lumbar Angles of Males and Females in Nine Positions and with the Pelvis in Posterior (P), Neutral (N) and Anterior (A) Tilted Postures

		Males			Females		
		P	N	A	P	N	A
Position							
1.	$\bar{x}$	5.2	18.7	30.4	7.4	19.9	35.4
	s	6.1	4.8	5.8	8.9	7.9	8.0
2.	$\bar{x}$	-13.2	-7.9	4.2	-7.6	-0.7	15.8
	s	6.8	6.6	9.1	6.2	6.6	8.1
3.	$\bar{x}$	-16.2	-15.1	-13.0	-11.6	-5.8	-1.5
	s	6.4	6.8	6.9	5.9	5.8	6.2
4.	$\bar{x}$	14.1	25.5	31.2	11.3	22.9	35.8
	s	8.8	8.4	7.7	11.5	9.9	9.1
5.	$\bar{x}$	2.0	-2.5	17.8	-8.0	3.3	26.3
	s	6.0	8.6	8.9	7.0	6.8	9.4
6.	$\bar{x}$	8.0	-5.6	10.2	-8.9	1.8	19.0
	s	5.4	6.6	8.7	6.9	5.7	7.3
7.	$\bar{x}$	-6.1	7.1	23.8	-2.9	8.1	31.2
	s	6.4	6.7	8.0	8.5	8.8	7.2
8.	$\bar{x}$	-8.5	0.0	17.2	-7.5	2.2	23.4
	s	7.4	6.6	11.1	6.2	7.0	9.3
9.	$\bar{x}$	17.4	-15.4	-11.8	-12.6	-8.3	-1.8
	s	5.6	6.6	8.8	5.7	4.6	6.7

TABLE 6.5

Mean and Standard Deviation Pelvic Angles of Males and Females in Nine Positions and with the Pelvis in Posterior (P), Neutral (N) and Anterior (A) Tilted Postures

		Males			Females		
		P	N	A	P	N	A
Position							
1.	$\bar{x}$	84.9	97.4	110.6	86.2	96.3	111.3
	s	4.4	4.5	5.6	5.6	5.0	4.8
2.	$\bar{x}$	69.4	76.1	87.6	69.0	79.9	92.9
	s	7.2	6.7	7.3	5.2	4.7	4.5
3.	$\bar{x}$	61.6	66.5	70.2	63.1	72.4	79.1
	s	7.9	7.3	8.5	5.4	5.2	6.9
4.	$\bar{x}$	94.1	103.4	112.2	88.9	100.0	111.8
	s	6.5	4.8	5.7	6.8	6.3	4.8
5.	$\bar{x}$	72.2	81.4	95.6	72.6	84.8	100.9
	s	5.2	8.2	7.6	7.4	5.5	5.5
6.	$\bar{x}$	70.1	77.7	89.0	69.0	80.7	94.6
	s	5.9	7.6	7.6	6.8	5.2	5.1
7.	$\bar{x}$	76.7	88.4	102.1	73.8	88.8	106.0
	s	7.2	6.7	7.6	7.4	5.6	4.4
8.	$\bar{x}$	70.4	81.9	94.4	72.4	84.9	100.4
	s	13.7	6.9	8.2	5.8	4.6	5.1
9.	$\bar{x}$	61.4	64.8	69.4	61.2	68.2	74.7
	s	7.1	6.8	8.3	16.1	5.2	4.9

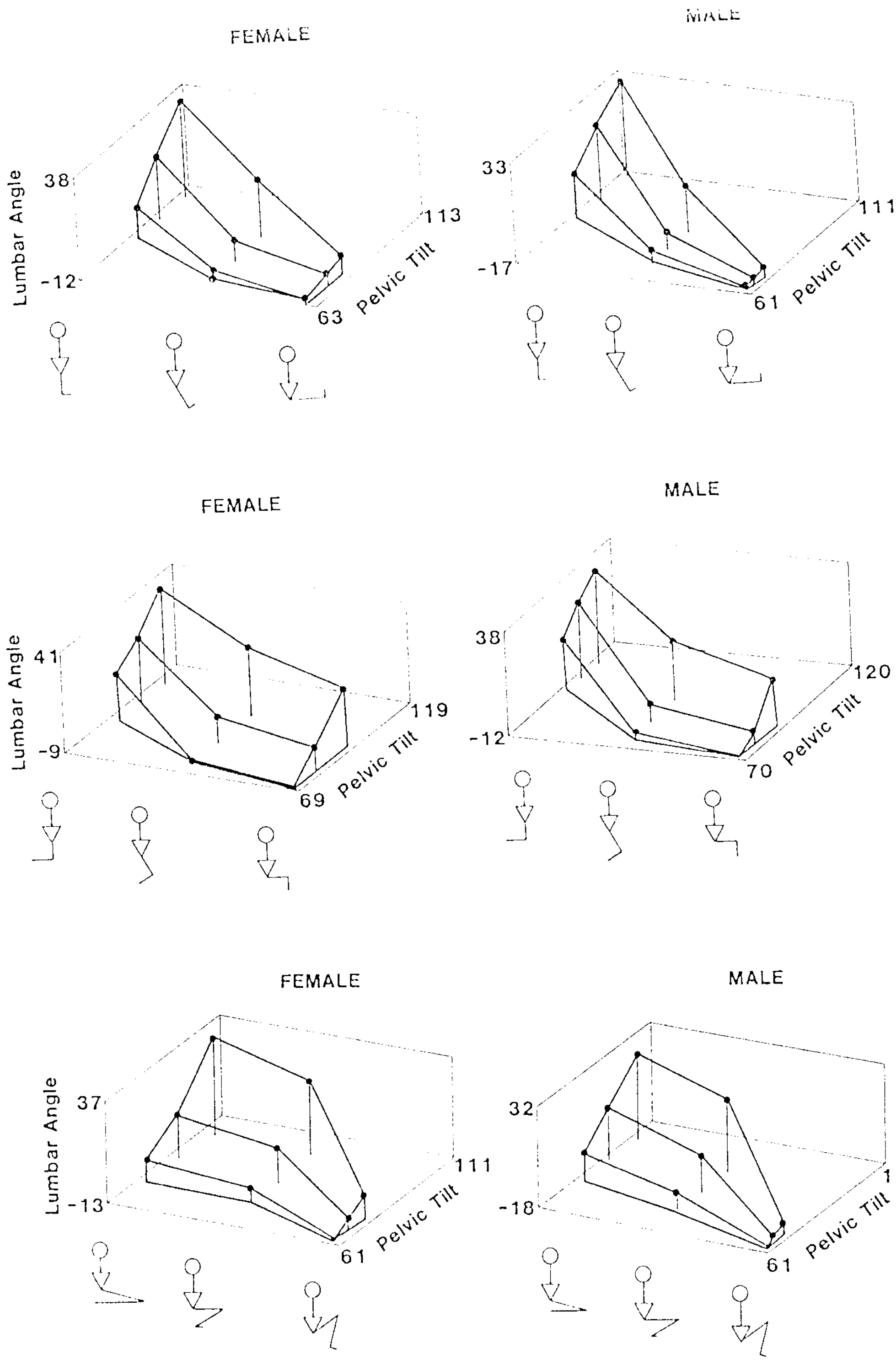


Figure 6.2 Lumbar angles and pelvic tilts of males and females in posterior, neutral and anterior pelvic postures in nine positions.

The data indicate that the range of movement of the pelvis and lumbar spine is position dependent. Each body position appears to have a particular relaxed posture and functional range of movement about it. The range of movement about the relaxed posture was greatest in standing, kneeling and sitting with kneepad and least in long sitting and semi-squatting.

In the unconstrained positions, the trunk can be maintained erect across a wider range of lumbar and pelvic angles. In constrained positions, this is not possible.

For example in constrained positions such as long sitting, the hamstrings are lengthened because the hip joints are flexed and the knees are extended. The 90 degree angle between the trunk and thighs in the erect position is only partly achieved by flexing the hips. The remaining postural adaptation takes place via posterior pelvic rotation. This has two effects, firstly, the lumbar angle is diminished by the posterior pelvic movement and secondly, the functional range of motion of the pelvis and lumbar spine is limited by the resistance to lengthening of the hamstrings (the iliopsoas muscle is shortened and less able to oppose the pull of the hamstrings).

In two-point kneeling, the hamstrings are shortened because the knee is flexed compared with standing. They are therefore weakened in relation to the iliopsoas muscles and the pelvis tilts anteriorly which increases the lumbar angle.

A muscular explanation for the effects of body position on spinal and pelvic angles and ranges of motion seems appropriate. Changes in hip and knee flexion change the lengths of the hip flexors and extensors which causes reversible imbalances between these muscles. Compensatory movements of the spine and pelvis are therefore required to maintain the trunk in an erect position.

In ergonomics, working positions are sometimes characterised by measuring the tilt of the pelvis and the posture of the spine. The present findings suggest that they may also be characterised in terms of the degree of constraint placed on these structures by the muscles. Table 6.6 presents lumbar angle in each body position as a percentage of the total range of lumbar flexion/extension (percentage fully extended in each position) together with the functional range of movement in the position. As can be seen, those body positions which give rise to lumbar angles towards the extreme of the total range of lumbar mobility also tend to be more constrained. For example, in the two-point kneeling, the lumbar angle is greater than in standing yet the range of motion in two-point kneeling is reduced. It may be stated, on the basis of the present data, that two-point kneeling constrains the lumbar spine anteriorly. In many of the sitting positions, the range of motion is also constrained, but it is constrained posteriorly. In kneeling (position 7), it can be seen that the lumbar angle is almost at the mid-point of the total lumbar range of movement (48.9 and 47.0% of maximum extension for males and females) and the functional range of lumbar movement in this position is large compared to most of the other positions.

In working situations it appears likely that attempts to move the trunk in the direction of the constraint would be stressful - it might be hypothesised that such constraint is related to postural stress and discomfort, particularly where operators work in fixed positions.

TABLE 6.6

Lumbar Angle (as a percentage of total range of lumbar extension*) in Nine Bony Positions and Range of Lumbar Motion in Each Position.

	Males		Females	
	Lumbar Angle (%)	Range	Lumbar Angle (%)	Range
Position				
1.	67.6	25.2	65.6	28.0
2.	25.0	17.4	33.1	22.8
3.	13.6	3.2	25.1	10.1
4.	78.3	17.1	70.2	24.5
5.	33.6	15.6	39.5	34.3
6.	28.7	18.2	37.1	27.8
7.	48.9	29.9	47.0	33.1
8.	37.6	25.7	37.4	30.9
9.	14.0	5.6	21.2	10.8

* Calculated using the mobility measures, as in experiment 1.

Mechanisms of Postural Adaptation 2: Analysis of the Standing Posture

The means and standard deviations of the muscle length and lumbar mobility measures are given in Table 6.7. Females appeared to have longer hamstrings than males although the lumbar mobility and iliopsoas lengths were similar. Using different methods, Troup et al. also found that females tended to have longer hamstrings while measures of lumbar mobility were similar in males and females.

Correlation matrices were calculated using the following variables: thoracic and lumbar angles, the angles of sacral and pelvic tilt, the muscle length indices and lumbar flexion and extension. The data were analysed separately according to sex, yielding separate matrices of Pearson product-moment correlation coefficients. Table 6.8 presents the results of the analyses. The data yielded several statistically significant correlations, summarised below.

TABLE 6.7

Means and Standard Deviations of Lumbar Angles and Muscle Indices (degrees)

	Males		Females	
	$\bar{x}$	s	$\bar{x}$	s
Hamstring Index	82.6	11.6	96.9	16.1
Iliopsoas Index	12.3	5.3	13.6	7.8
Lumbar Flexion	-23.6	8.3	-21.8	7.6
Lumbar Extension	39.1	9.7	41.8	4.2

TABLE 6.8

Correlation Matrices of Spinal and Pelvic Angles and Muscle Indices in Standing

Females

	TK	LL	ST	PT	HI	II	LF
Thoracic Angle TK							
Lumbar Angle LL	0.30						
Sacral Tilt ST	-0.12	0.85*					
Pelvic Tilt PT	-0.02	0.06	0.01				
Hamstring Index HI	-0.49*	-0.37	-0.26	-0.37			
Iliopsoas Index II	-0.26	-0.51*	-0.40*	-0.55*	0.50*		
Lumbar Flexion LF	0.19	0.41*	0.26	-0.14	0.01	-0.09	
Lumbar Extension LE	0.21	0.37	0.35	-0.22	-0.34	-0.42*	-0.08

Males

	TK	LL	ST	PT	HI	II	LF
Thoracic Angle TK							
Lumbar Angle LL	0.22						
Sacral Tilt ST	-0.18	0.68*					
Pelvic Tilt PT	-0.31	0.27	0.60*				
Hamstring Index HI	-0.17	-0.17	-0.08	-0.18			
Iliopsoas Index II	-0.01	-0.36	-0.37	-0.44*	0.45*		
Lumbar Flexion LF	-0.09	-0.02	0.07	-0.05	-0.08	0.05	
Lumbar Extension LE	-0.21	0.23	0.08	-0.03	0.20	0.32	0.06

* For 23 degrees of freedom, correlations greater than 0.396 and 0.505 are statistically significant ($p<0.05$ and $p<0.01$ respectively)

Standing Lumbar Angle

Females. The lumbar angle correlated positively with sacral tilt (the L5/S1 angle) and negatively with the iliopsoas index and with lumbar flexion. Lumbar angle did not correlate significantly with pelvic tilt. The lumbar curve is generally held to arise at the sacrum which is in accord with these observations. Also, the data suggest that females with shorter muscles have more pronounced lumbar lordosis in stance. However, there was no significant correlation between pelvic tilt and lumbar lordosis. This is in agreeement with the findings of Walker et al. (1987). The relationship between pelvic tilt and lumbar angle in stance may be more complex than is sometimes assumed.

Males. Lumbar angle correlated positively with sacral tilt but not with any of the other variables.

Standing Pelvic Tilt

Females. A positive correlation was found between the iliopsoas index and pelvic tilt. Pelvic tilt did not correlate significantly with sacral tilt, lumbar angle or the hamstring index.

Males. Pelvic tilt correlated positively with sacral tilt and with the iliopsoas index.

Muscle Indices

The hamstring index correlated positively with the iliopsoas index in both males and females. Toppenberg and Bullock (1990) found hamstring length to correlate positively with iliopsoas length. The present findings are in agreement with this and suggest that there is an interrelationship or balance in the development of these muscles in healthy subjects.

Lumbar Mobility Measures

Few of the correlations between the lumbar mobility indices and the other variables were statistically significant. In the case of males, no statistically significant relationships were found. In the case of females, lumbar flexion correlated positively with lumbar angle and lumbar extension correlated negatively with iliopsoas length.

Pelvic Tilt and Lumbar Angle

For neither sex did pelvic tilt correlate significantly with lumbar angle. That is, anterior pelvic tilt in stance is not associated with increased lumbar angle.

This is somewhat surprising since most authors generally consider the relationship between these two variables to be strong (e.g. Day et al., 1984). The absence of a significant correlation warrants some discussion since it may influence the interpretation of the present findings.

Figure 6.3 shows tracings from radiographs of the lumbosacral region of the author in stance and when sitting with 65-degree and 90 degree trunk-thigh angles. The differences in posture concur with the results of the previous experiment - lumbar lordosis is accompanied by an increased sacral angle and the position of the iliac crests strongly suggests that this is accompanied by anterior pelvic tilt. It is clear from this and from the data in Tables 6.4 and 6.5 that the pelvic and lumbar angles do change together when the position of the body changes, i.e. a change in the tilt of the pelvis is accompanied by a change in the shape of the spine. Therefore the pelvic tilt measure used here can be used in a relative sense, to quantify changes in body position.

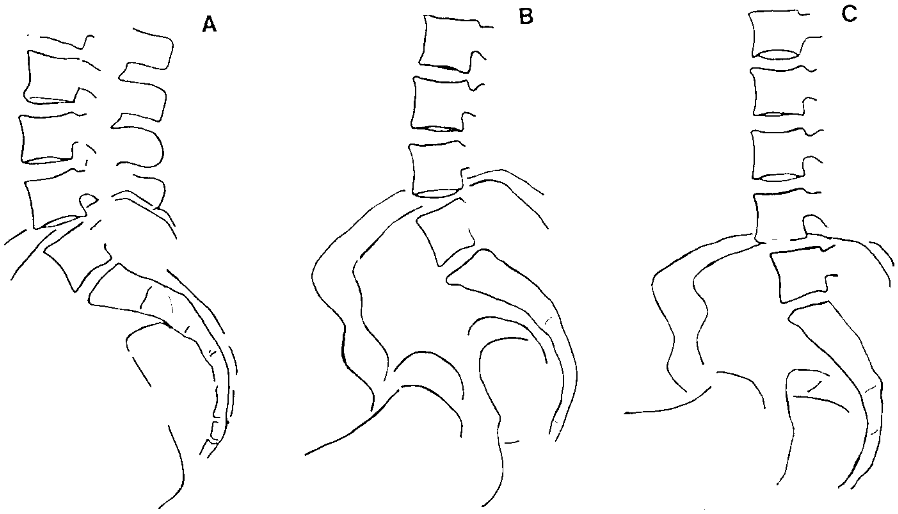


Figure 6.3 Tracings from radiographs of the lumbosacral region of the author in stance (a) and when sitting with 65-degree (b) and 90-degree (c) trunk-thigh angles.

However, the present data suggest that within a given position (in this case standing) the relationship between pelvic tilt and lumbar angle is not strong across subjects.

This is unlikely to be due to measurement problems since the method of measuring pelvic tilt has been shown to be reliable in this and other investigations - unless the method lacks validity.

Walker et al. (1987) also failed to find a positive relationship between pelvic tilt and lumbar angle using this method of measuring pelvic tilt. Some researchers (e.g. Toppenburg and Bullock, 1986) measure the angle of a line between the PSIS and the symphysis pubis as an index of pelvic tilt. In the light of the anatomical discussion above concerning the points of action of the muscles attached to the pelvis, this method may be more valid and merits further investigation.

A further possibility is that anatomical factors can weaken the relationship between pelvic tilt and lumbar angle across subjects. It is known that the angulation of the articular facet of the sacrum strongly influences lumbar angle (Kapandji, 1970). The strength of any correlation with pelvic tilt is not known although in the present study, sacral tilt (which may reflect the angulation of the articular facet) correlated with pelvic tilt in males but not in females. Further information on the normal variability of articular facet angulation and how it influences the interpretation of pelvic tilt would be of use both in clinical settings and for modelling purposes.

Finally, since iliopsoas consists of two muscles, psoas major and iliacus which attach to the lumbar spine and ilium respectively, it is possible that the length of these two muscles may vary to a differing degree between individuals so as to weaken the relationship between pelvic tilt and lumbar angles in standing. For example, shortness in psoas major might increase the lumbar angle more than the pelvic tilt. This would explain why the correlation between lumbar angle and sacral tilt is significant as opposed to that between lumbar angle and pelvic tilt.

Mechanisms of Postural Adaptation 3: Role of the Muscle Indices

Significant correlations between muscle indices and spinal and pelvic angles in standing were obtained. However, a previous finding of a significant correlation between hamstring index and lumbar angle was not replicated, although the correlation coefficients were in the expected direction (i.e. negative).

However, the analysis indicated the presence of a relationship between pelvic tilt and the iliopsoas index. Table 6.9 gives the results of linear regression analyses of iliopsoas index and pelvic tilt in standing.

TABLE 6.9

Linear Regression Analyses of Iliopsoas Index and Pelvic Tilt (degrees) in Standing

	Y-Intercept	Slope	Correlation	F-Ratio
Males	101.99	-0.37	-0.44	5.36**
Females	100.60	-0.35	-0.55	9.48*

* statistically significant, p<=0.01
** statistically significant, p<=0.05

These findings support the model of posture described earlier. Of interest is the similarity between the slopes and intercepts of the regression equations for males and females - similar to the finding of the previous experiment in a regression analysis of sacral tilt and lumbar angle. It would appear that the pelvic tilts and lumbar angles of males and females are similar in standing and are similarly influenced by natural variation in muscle length. The main difference between males and females would seem to lie in the adaptation of the spine and pelvis to different working positions due to differences in muscle length and not spinal mobility (Table 6.6).

Change in Pelvic Tilt. The previous analysis indicates that a significant proportion of the variation in pelvic tilt between individuals of the same sex can be accounted for by variation in iliopsoas length. Further, the data in Tables 6.4 and 6.5 indicate that the tilt of the pelvis, the lumbar angle and their ranges of movement vary considerably between different working positions. It has been hypothesised that the postural adaptation of the pelvis to a particular working position will be a function of muscle length. To test this prediction, an analysis of change in pelvic tilt and lumbar angle was carried out, using standing as the reference posture. This was done for each of the 8 working postures. First, a multiple regression analysis using the "step-up" approach was used with change in pelvic tilt as the dependent variable and the hamstring and iliopsoas indices as potential predictors. Table 6.10 presents the results of the analyses.

As can be seen from Table 6.10, the iliopsoas index was selected as the best predictor of the postural adaptation of the pelvis in the regression models.

For females, the hamstring index did not contain information that further reduced the residuals significantly. For males, the hamstring index was the best predictor of the posterior pelvic tilting which occurred when the long sitting position was adopted (partial correlation 0.74) although the iliopsoas index was also statistically significant. Also, in the sitting with kneepad and the semi-squatting positions the hamstring index, although not the best predictor, contributed to further reductions in the residuals. These different findings for males and females are of interest when it is recalled that females appear to have longer hamstrings than males (Table 6.6). It is noteworthy that the anterior pelvic tilting which occurred in the two-point kneeling position was not systematically related to either of the muscle length indices. Presumably, the hamstrings are shortened equally across the subjects in this position and therefore the incremental increase in pelvic tilt is also the same across subjects.

TABLE 6.10

Linear Regression Analyses of Change in Pelvic Tilt and Iliopsoas Index

Position	Y-Intercept	Slope	Partial Correlation	F-Ratio
			Males	
2.	-30.00	0.70	0.57	11.50*
3.	-40.10	0.75	0.55	10.55*
4.	4.10	0.15	0.08	1.17
5.	-30.73	1.20	0.71	25.00*
6.	-28.90	0.76	0.53	10.29*
7.	-12.60	0.30	0.15	1.55
8.	-28.50	1.06	0.67	20.05*
9.	-43.02	0.81	0.63	18.40*
			Females	
2.	-20.90	0.33	0.41	4.81**
3.	-30.47	0.48	0.57	11.20*
4.	5.68	-0.15	0.26	1.70
5.	-15.49	0.29	0.54	11.41*
6.	-21.03	0.40	0.65	18.1*
7.	-13.30	0.42	0.44	5.69**
8.	-27.75	0.80	0.65	18.88
9.	-36.37	0.29	0.59	13.83*

* Statistically significant P<0.01
** Statistically significant P<0.05

These findings are of interest because they emphasise the importance of the iliopsoas rather than hamstrings as a determinant of posture and postural adaptation in healthy individuals despite the intercorrelations between the variables.

Anatomically, the data can be interpreted as follows: the severity of an individual's anterior pelvic tilt in stance is influenced by the iliopsoas muscle. As the hip flexes, the iliopsoas shorten and permit the pelvis to tilt posteriorly. Individuals with short iliopsoas will have increased anterior pelvic tilt when standing. This anterior tilt will be lost rapidly as soon as the hip begins to flex.

TABLE 6.11

Linear Regression Analyses of Change in Pelvic Tilt and Change in Lumbar Angle in Different Working Positions

Position	Y-Intercept	Slope	Partial Correlation	F-Ratio
		Males		
2.	-14.56	0.54	0.43	5.17**
3.	-8.14	0.82	0.67	19.07*
4.	6.60	0.44	0.05	0.06
5.	-7.70	0.75	0.73	25.60*
6.	-7.10	0.85	0.67	18.93*
7.	-5.80	0.58	0.56	10.45*
8.	-3.91	0.93	0.87	72.60*
9.	-19.98	0.44	0.40	4.49**
		Females		
2.	-7.87	0.75	0.52	8.15*
3.	-8.43	0.75	0.54	9.27*
4.	0.99	0.55	0.37	3.69
5.	-7.08	0.83	0.69	20.62*
6.	-7.06	0.69	0.54	9.61*
7.	-3.30	1.11	0.79	38.46*
8.	-8.10	0.76	0.57	11.28*
9.	-0.91	0.94	0.61	13.87*

* Statistically significant P<0.01
** Statistically significant P<0.05

Pelvic Tilt and Lumbar Angle. Table 6.10 gives the results of linear regression analyses of change in lumbar angle as a function of change in pelvic tilt. All of the regression equations were significant except those for position 4, two-point kneeling. Essentially this illustrates that the spine and pelvis move together and that more postural adaptation takes place in the spine in individuals with shorter muscles than in those with long muscles.

Conclusions

The hypothesis that spinal and pelvic angles are determined by body position was confirmed using a large variety of body positions. Lumbar angles in the various positions ranged from 14% to 78% of maximum lumbar extension as evaluated by tests of lumbar mobility. Analysis of body position is therefore a key consideration in the evaluation of spinal stress in the workplace.

Body position was found to influence the functional range of motion of the spine and pelvis as well as their resting positions. It appears the more the lumbar angle is towards the extremes of the range of lumbar mobility, the more restricted is the functional range of motion of the spine and pelvis. Evidently, the lumbar spine and pelvis may be constrained in extended, anteriorly tilted postures as well as flexed, posteriorly tilted postures. Particular body positions appear to cause functional "imbalances" between the muscles which cause postural deviation and constraint.

The hypothesis that change in pelvic angle is related to hamstring stretch in sitting received little support. The iliopsoas index accounted for more of the variation in postural adaptation to sitting than did the hamstring index in almost all the positions.

Supplementary investigations of the role of the hamstrings and of the hip and trunk muscles are reported in the following chapter.

7. SUPPLEMENTARY INVESTIGATIONS

Two supplementary investigations were carried out to provide further insights into the findings of the previous experiments. Firstly, a re-analysis of some of the data of experiment 2 was carried out in order to investigate the role of the hamstrings in posture. Secondly, an electromyographic investigation was carried out on the role of the hip and trunk muscles in different body positions.

Role of the Hamstrings

A supplementary investigation was carried out to examine the influence of muscle length on pelvic range of motion - particularly the role of the hamstrings in limiting the range of anterior pelvic tilt in a given position.

The data from experiment 2 were re-analysed. The muscle length and lumbar mobility indices were correlated with the anterior and posterior ranges of pelvic motion in each of the nine working positions. Range of motion was calculated as the difference (in degrees) between the anterior and posterior pelvic tilts and the neutral tilt in each of the nine working positions.

Factors Related to Anterior Pelvic Mobility

For females, statistically significant (Pearson product-moment) correlations were obtained between the hamstring index and anterior pelvic tilt range in standing and in the two long sitting positions ($r = 0.46$, 0.49 and 0.45 respectively, $p<0.05$).

For males, significant positive correlations were found between the hamstring index and anterior pelvic tilt range in standing, in the two long sitting positions and in two-point kneeling ($r = 0.44$, 0.65, 0.42 and 0.41 respectively, $p<0.05$). Additionally, the lumbar extension index correlated significantly with anterior tilt range in the kneeling position ($r = 0.48$, $p<0.05$).

None of the remaining correlations between anterior pelvic tilt and muscle indices were statistically significant.

Factors Related to Posterior Pelvic Mobility

For females, none of the correlations approached statistical significance.

For males, significant correlations were found between the hamstring index and posterior pelvic tilt in two-point kneeling, kneeling and sitting with kneepad ($r = 0.50$, 0.55 and 0.40 respectively, $p<0.05$). The iliopsoas index correlated significantly with posterior tilt in open sitting ($r = 0.62$, $p<0.05$). The lumbar flexion index correlated negatively with posterior tilt in long sitting ($r = -0.43$, $p<0.01$).

Interpretation

Anterior movement of the pelvis is influenced by hamstring length in certain positions of the body. When the knee is extended, the hamstring index correlated with anterior tilt range - subjects with greater hamstring indices were able to tilt the pelvis further forwards than those with smaller hamstring indices. This suggests that these muscles have a major influence on postural adaptation to seats when the knees are extended. The constraining influence of the hamstring muscles is likely to increase the flexion strain on the lumbar spine when a person leans forwards to work at a desk. This will be more pronounced in those with short hamstrings.

The findings for the analysis of the posterior tilt range data are less clear cut. The iliopsoas index did not correlate systematically with posterior tilt range with the knees flexed or extended. There was little evidence to suggest that the iliopsoas muscles restrain the posterior movement of the pelvis in the positions studied.

The indices of lumbar mobility correlated significantly with pelvic range in few positions. It is likely that lumbar mobility is a less significant factor than muscle lengths in determining postural adaptation to furniture.

Qualitative Electromyographic Investigation of Hip and Trunk Muscles

In the previous experiment, it was demonstrated that in some positions of the body, the trunk can be maintained in an erect position over a wide range of pelvic and lumbar angles. In other positions, the range of angles was very limited. This was discussed in terms of the constraint imposed by the muscles, particularly when one muscle was lengthened or stretched and its antagonist shortened.

Following Gracovetsky and Farfan (1986) and Ladin et al. (1989) who have applied systems theory and optimisation concepts to the study of the spine, it may be hypothesised that each working position defines as "space" of the total trunk and hip muscle activity required for pelvic and spinal stabilisation. The neutral posture would be that which minimises the required activity. In unconstrained positions, the space would resemble a shallow valley with a large neutral region whose maintenance required minimum muscle activity. In constrained positions, the minimum would be at the bottom of a steep, ravine-like space in which even small shifts in the posture of the spine and pelvis would require large amounts of muscle activity.

A qualitative electromyographic (EMG) investigation of these notions was therefore carried out using five female and four male subjects.

Method

Five female and four male subjects from the same population sampled previously participated.

Electromyographic measurements were made using a commercially available system (the EM8 electromyograph system, Plexus Electromedical, 1989).

Surface (silver chloride) electrodes were placed unilaterally on the following skin sites to detect electrical activity of the following muscle groups:

1. Erectores Spinae: Adjacent to the vertebral column over the body of the muscle at the level of L3 (approximately 3cm from the midline of the back with interelectrode distance of approximately 5cm).

2. Abdominals (rectus abdominis): On the midline of the body between the umbilicus and the xiphisternum (interelectrode distance approximately 5cm).

3. Hamstrings/Gluteals: Below the gluteal crease and above the popliteal fossa (interelectrode distance approximately 15cm). A large interelectrode distance was needed to overcome practical problems at the seat/buttock interface encountered during the investigation of sitting postures.

4. Iliopsoas: Over the inguinal canal. Iliopsoas activity is difficult to measure using surface electrodes because of the depth of many of the fibres (e.g. the vertebral portion of

the psoas muscle) and the presence of other muscles. This measure therefore reflects general hip flexor activity (interelectrode distance approximately 5 cm).

Each muscle group was allocated to a single electrical channel. Two electrodes per channel were used. The patella was used as the electrical earth.

After amplification and digitisation, the signals were fed to an Olivetti M24 personal computer. The EM8 software was run under MS DOS.

Subjects adopted a number of body positions in random order. In each position, they were asked to sit erect in a relaxed manner. This was taken as the neutral position of the pelvis and pelvic tilt and EMG measurements were made. They were then asked to make maximum voluntary posterior and anterior pelvic tilts, holding each for five seconds while measurements were made. This was followed by submaximal posterior and anterior tilts at a level of effort judged by the subjects to be sustainable for approximately one minute without discomfort. A period of one minute was used, based on the data of Kroemer (1970) which demonstrated the exponential decay of endurance time as a function of force - i.e. an effort sustainable for one minute differs greatly from both a maximal exertion and from resting, according to Kroemer's data.

With the subjects holding these postures for five seconds, EMG and pelvic tilt measurements were made as described below.

All four EMG channels were displayed on the screen simultaneously. The smoothed and rectified signals were displayed visually in "oscilloscope" format and the sweep rate (time taken by the trace to return to its starting position) was set to 5 seconds.

In each of a number of body positions, subjects observed the screen and carried out the anterior and posterior pelvic tilts in time with the sweep rate of the system. That is, at the commencement of the first sweep, subjects would relax for the duration of that sweep. This gave data on the EMG activity of each of the four muscle groups with the subject in a relaxed position. At the beginning of the next sweep, subjects would execute a pelvic tilt, holding it for the duration of the sweep. They would then relax for the duration of the next sweep and then execute the next pelvic tilt. At the same time, measurements of pelvic tilt were manually recorded.

In this way parallel data on pelvic tilt and EMG activity were obtained for each posture adopted in all of the body positions. At the end of each sweep, the EM8 system presented an integrated value for each muscle group.

Thus, for each muscle group and each pelvic tilt, an index of EMG activity was obtained in each of several body positions.

Results and Discussion

The EMG data were normalised for each of the subjects - the integrated values were expressed as a percentage of the maximum value for each subject and muscle group. The pelvic angles were also normalised for each subject.

Each pelvic angle was expressed as a percentage of the total pelvic range of motion across all body positions (maximum posterior tilt being 0% and maximum anterior tilt 100%).

Thus, for each subject, each pelvic angle and EMG value from a given muscle group could be expressed in a normalised fashion to control for differences in muscle length and skin impedance.

Data from the following 5 body positions are presented (The previous experiment suggested that these positions constituted a wide range of neutral (i.e. relaxed) lumbar and pelvic angles.)

1. Two-point Kneeling
2. Standing
3. High Sitting (sitting on a high stool with knees extended)
4. 90-degree Sitting
5. Long Sitting

<u>Data Presentation</u> For each of the body positions investigated, 5 data sets were obtained. These consisted of a normalised value of pelvic tilt together with normalised EMG data for each of the muscle groups monitored. Thus, for each body position, pelvic angles and muscle activity in the neutral posture and in two anterior and two posterior tilted postures were obtained.

For each body position, it was therefore possible to plot normalised EMG against pelvic angle in the different pelvic postures and to examine the shape of the plot to determine whether alterations in pelvic tilt were accompanied by alterations in the EMG activity of a particular muscle group.

Since the data were normalised on both variables, it was possible to combine across subjects.

<u>Abdominal Muscle EMG</u>

Figure 7.1 presents normalised abdominal EMG plotted against pelvic angle in the 5 body positions.

There are pronounced differences in EMG activity between the different positions which may be due to difference in muscle

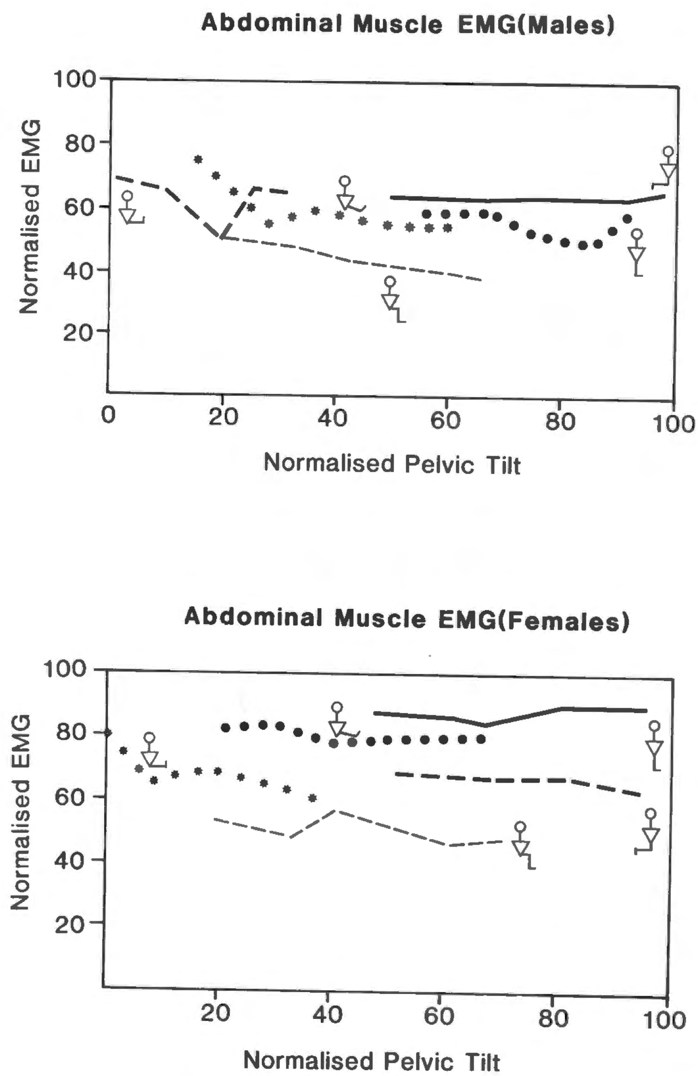


Figure 7.1 Abdominal muscle EMG in neutral, anterior and posterior pelvic postures in 5 body positions (males and females). Note the lack of systematic changes in the EMG activity as a function of pelvic tilt in each of the body positions.

lengths or skin thickness, but few systematic differences as posture changes within a body position. The abdominal muscles do not appear to be involved in pelvic tilt and lumbar flexion or extension in the positions studied. For this reason, abdominal muscle activity was excluded from the rest of the analysis.

Hamstring/Gluteals

Activity from this muscle group was mainly observed when subjects tilted the pelvis posteriorly in the standing and two-point kneeling positions. In the sitting positions the EMG from this muscle group was flat across the pelvic postures. This is a very interesting result in the light of the previous discussion of the role of the gluteal muscles in the evolutionary remodelling required for the attainment of bidepdalism.

Iliopsoas/Erectores Spinae

In standing, the erectores spinae appeared to be involved in tilting the pelvis forwards. Activity from both muscle groups was observed in sitting.

Muscle Activity Spaces

Figures 7.2 to 7.6 depict EMG activity spaces for subjects in relaxed postures and with the pelvis tilted in two anterior and two posterior postures. Spaces are depicted for each body position.

The data are suggestive and provide preliminary support for the optimisation notions discussed previously. In constrained positions of the body, the muscle activity spaces are more ravine-like and the minimum (or neutral) region is small. Note that minima do seem to occur simultaneously between muscle groups - that is, for all body positions there is a point or region at which the muscle activity is simultaneously minimum or close to

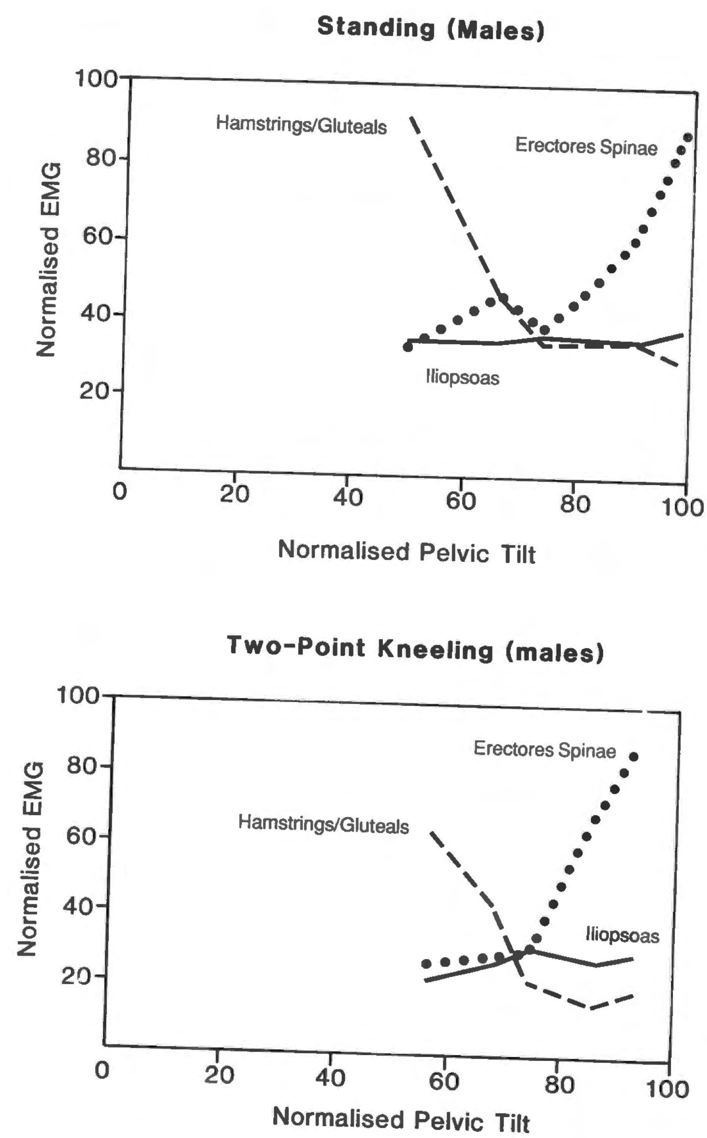


Figure 7.2 EMG activity for males in standing and in two-point kneeling. Erectores spinae EMG increases on anterior pelvic tilting in both positions. Hamstring and gluteal EMG increases when the subjects tilt the pelvis posteriorly. In two-point kneeling, the EMG activity space is more "ravine-like" suggesting increased constraint

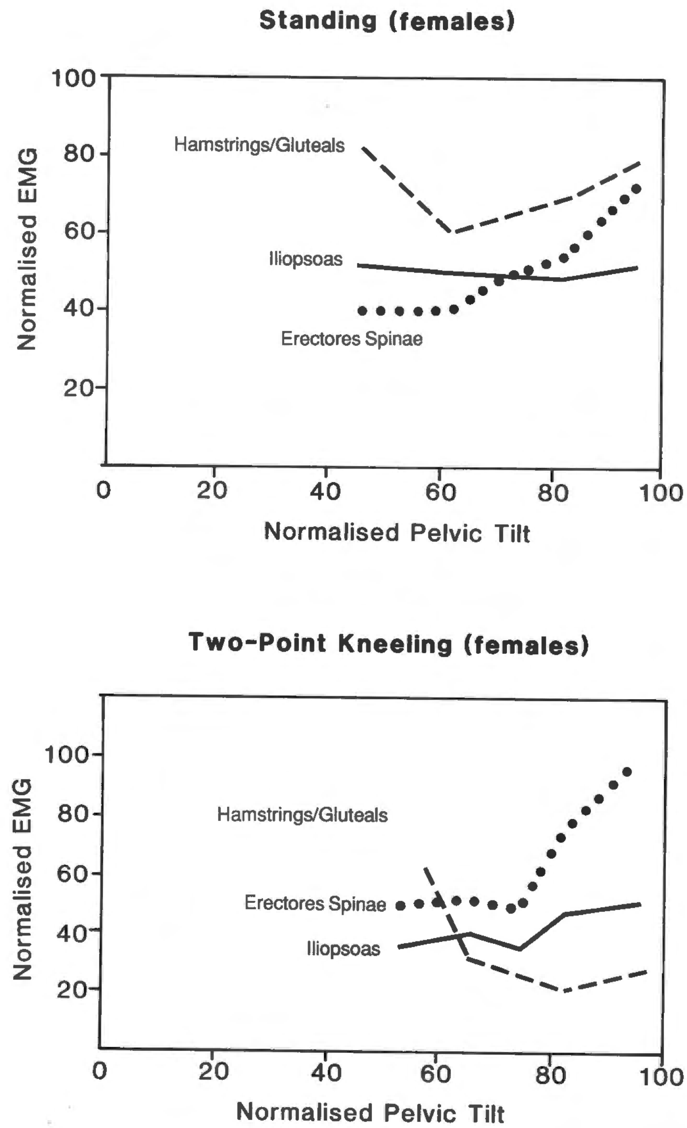


Figure 7.3 EMG activity for females in standing and in two-point kneeling. Note that in both positions, the EMG activity spaces are more "valley-like" in females than in males suggesting less constraint on the spine and pelvis. Two-point kneeling still appears to be more "ravine-like" in females than standing.

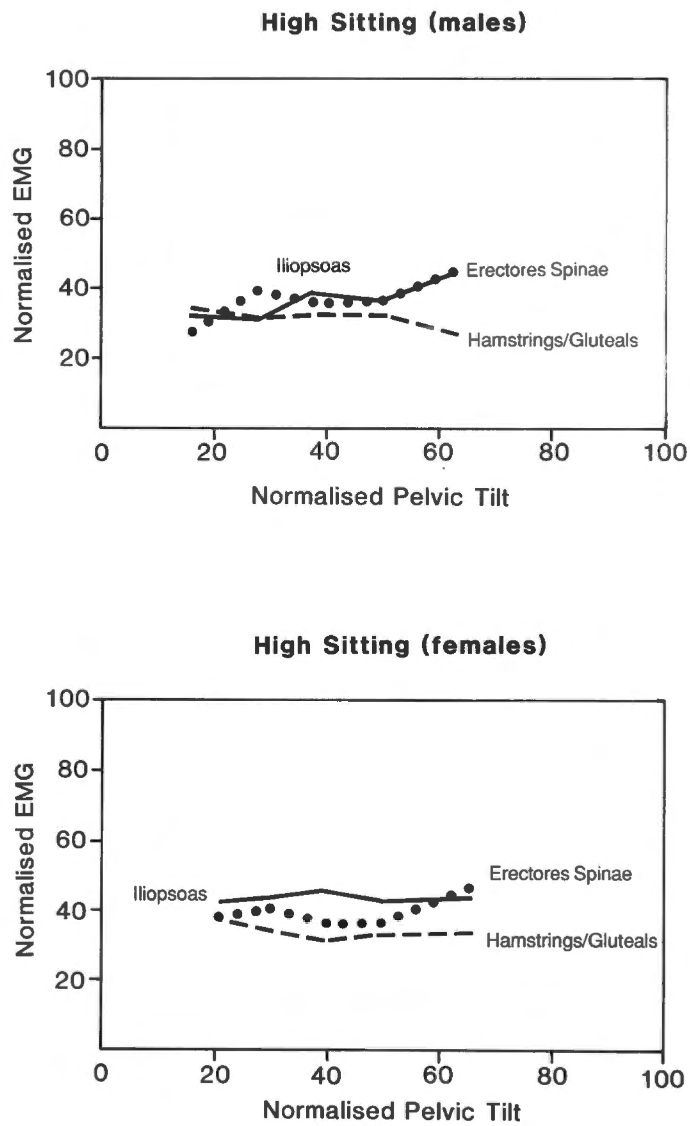


Figure 7.4 EMG activity for males and females in high sitting. Note the flat profile of the EMG activity space in relation to pelvic tilt suggesting a lack of constraint.

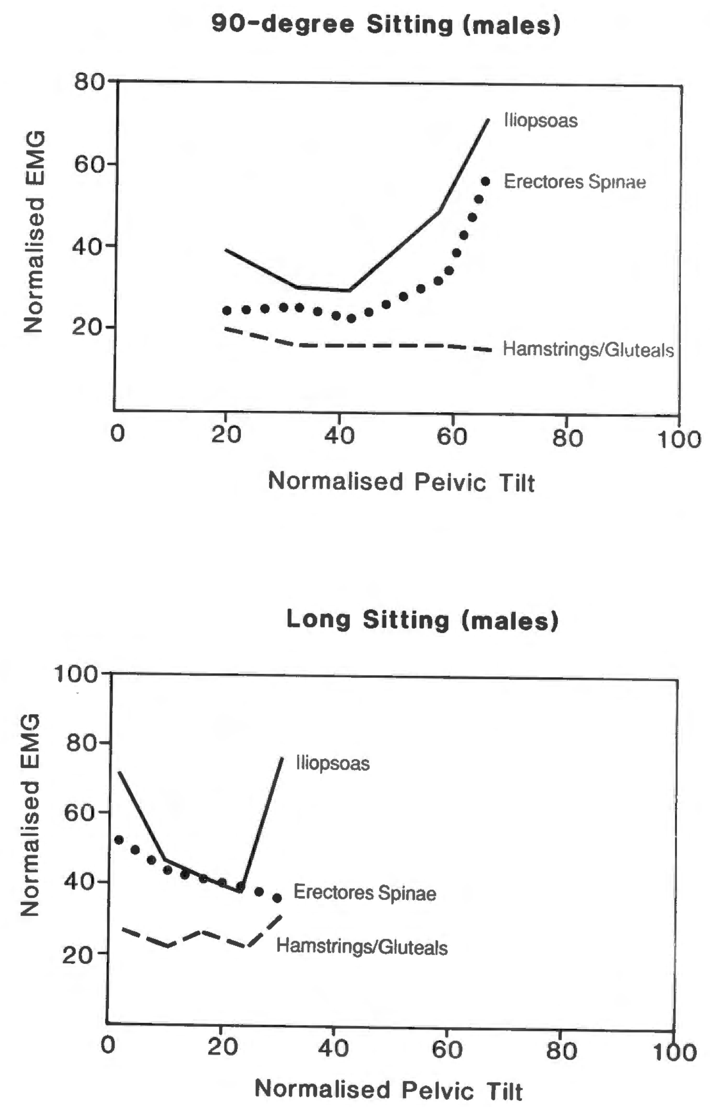


Figure 7.5 EMG activity for males in 90-degree and long sitting. Note the increase in iliopsoas as well as erectores spine activity when pelvis is tilted forwards. The asymmetric shape of the space for 90-degree sitting can be related to the notion of sitting as being "posteriorly constrained" as discussed in a previous chapter. In long sitting the EMG activity space is "ravine-like" and shifted posteriorly in terms of pelvic tilt.

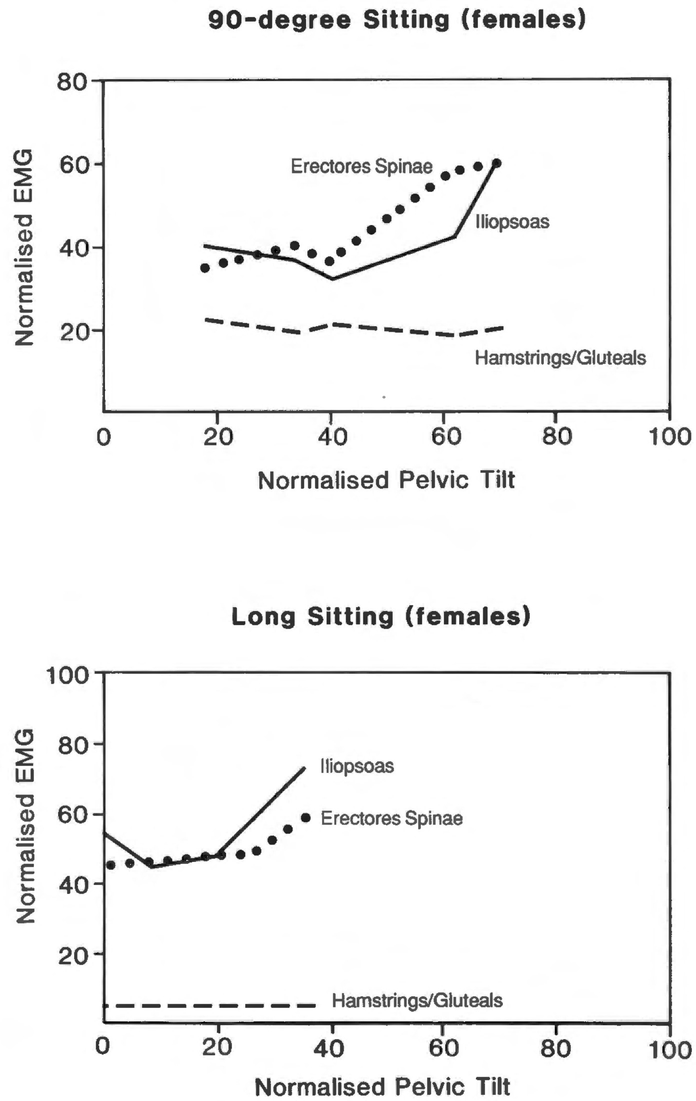


Figure 7.6 EMG activity for females in 90-degree and long sitting. Again the spaces are more "valley-like" in females then in males but the qualitative differences between the two positions are similar in both sexes.

minimum in all 3 muscle groups.

Although the data do not permit muscle forces to be inferred from the EMG activity, the conclusion of the previous experiment, that of body positions to be analysed in terms of the degree of constrainment they impose, has received additional support.

Conclusions

A supplementary analysis revealed that the hamstring index correlated significantly with anterior pelvic tilt range in a number of body positions in which the knees were extended. Subjects with long hamstrings were able to tilt the pelvis further forwards than those with short hamstrings.

This suggests that the pelvis is constrained posteriorly by the hamstrings in these positions. Sedentary workers are often advised to tuck their feet under the chair when leaning forward to work at a desk. The present findings suggest that the practice is valid since more trunk flexion will then be possible through anterior pelvic rotation rather than flexion of the lumbar spine. Some sedentary workers (e.g. pilots, drivers) are unable to flex the knees due to lack of space underneath the seat or having to operate pedals. The rest of the workspace, particularly the positioning of controls and displays, should be designed to minimise trunk flexion because of the resistance to anterior movement of the pelvis.

A preliminary electromyographic investigation provides some support for the optimisation notions introduced earlier. It it is accepted that a criterion of postural control is stress minimisation over the entire linkage (as Gracovetsky and Farjan, 1986, have suggested), this would explain why individuals often adopt postures which impose undue stress on localised areas - for that particular "postural space", the posture might minimise the average stress level over the entire linkage.

8. EXPERIMENT 4. Replication of the Main Findings and an Evaluation of Some Practical Implications

Introduction

The previous findings suggest that during stance, pelvic tilt depends on the iliopsoas muscle, whereas postural adaptation depends on the complete system of muscles of the trunk and hip. Any particular role of the hamstrings appears to be secondary as is readily apparent in postures where the knee is extended and the subject attempts to tilt the pelvis forwards.

This interpretation is arguably more in accord with the earlier anthropological discussion about the origins of the upright posture in man and the role of the lumbar lordosis and the muscles of the trunk and hip. Apart from any theoretical interest, acceptance of the interpretation has practical implications. A replication of the main findings on which the interpretation was based was therefore attempted using 15 male and 15 female subjects (Table 8.1). A number of potential design guidelines were also investigated.

Method

Experimental Design and Procedure

The experiment was in two parts. First, measures of muscle length were made together with measures of spinal angles and pelvic tilt in stance. This data was obtained in order to replicate the main findings of experiment 2.

In the second part of the experiment, a repeated measures design was used to evaluate the effects of some potential workspace design guidelines on posture. Spinal angles and pelvic tilts were measured in a control position and in an experimental position designed to simulate the implementation of a particular guideline. The positions were as follows:

1. Standing. Neutral, anterior and posterior pelvic tilts were measured when standing with the feet shoulder width apart and again when the right foot was placed on a footrest. The footrest was angled at approximately 15 degrees to the horizontal, raising the foot approximately 25 cm above the level of the floor. Experiment 2 led to the hypothesis that this would shorten the right iliopoas muscle and lengthen the gluteals resulting in a net posterior pelvic tilt.

2. Forward Sloping Chair with Kneepad. Spinal angles and pelvic tilts were measured when subjects sat on a forward sloping chair in upright, forward leaning and backward leaning postures. The effects of a sloping worksurface were also evaluated. A conventional chair was used as a control condition. In particular, it was hypothesised that postural adaptation to reclining would occur in the lumbar spine when the forward sloping chair was used and in the pelvis when the conventional chair was used, due to the anterior pelvic constraint imposed by the forward sloping chair.

3. Modified Industrial Stool. Spinal angles and pelvic tilts were measured with subjects sitting on a modified industrial stool (Figure 8.1). The stool was fitted with a wedge shaped-cushion to enable the thighs to point downwards slightly. Flexion of the knees enabled the feet to be placed on a footrest situated so as to position the ankles directly below the ischia. Neutral, anterior and posterior pelvic tilts and lumbar angles were measured when sitting on the stool and in a control condition - sitting on a forward sloping chair with kneepad. It was hypothesised that there

would be no difference in posture between the two seats. Additionally, the effect of flexing and extending the knees in the upright position and in forward leaning was investigated.

TABLE 8.1

Means and Standard Deviations of Subject Age, Height and Weight

	Males (N=15)		Females (N=15)	
	$\bar{x}$	s	$\bar{x}$	s
Age (yrs)	23.3	9.4	20.7	1.7
Height (cm)	179.1	4.5	171.3	5.4
Weight (kg)	73.9	6.4	59.1	6.1

In all cases, workspace dimensions were adjusted to suit subject body dimensions according to the guidelines of Floyd and Roberts (1958).

Results and Discussion

<u>Relationships Between Spinal and Pelvic Angles and Spinal Angles and Muscle Lengths in Standing</u>

An attempt was made to replicate the findings of experiment 2 in which significant correlations between some of the muscle length and spinal mobility indices and the spinal angles and pelvic tilt were obtained.

Matrices of the correlations between these variables were generated separately for males and females. Table 8.2 presents the results of these analyses. Table 8.3 presents data on lumbar mobility and muscle length.

When correlating several variables against one another, it is possible that spurious results will be obtained because some of the correlations will be statistically significant by chance. Type I errors (rejecting the null hypothesis when it is true) and type II errors (failing to reject the null hypothesis when the alternative is true) are possible.

The probability of a type-I error is the level of significance used to test the null hypothesis. The probability of a type-II error cannot be computed in the absence of a specific alternative. In comparing the findings of the replication with those of experiment 2, it must be remembered that some of the correlations will be statistically significant by chance and others will **not** be statistically significant by chance. However, it may be stated that the probability of making the same type-I error in two independent trials is very low -the product of the probability of making the error in each trial. Only correlation coeffiecients which were statistically significant in both trials will be discussed for this reason.

Females. Lumbar angle correlated positively with sacral tilt in both analyses, as might be expected. It also correlated positively with lumbar flexion. Females with greater flexion mobility of the lumbar spine therefore appear to stand with a more pronounced lumbar angle. Lumbar angle correlated negatively with the iliopsoas index. This suggests that female subjects with shortened iliopsoas muscles have more pronounced lumbar lordosis in stance.

The hamstring index correlated positively with the iliopsoas index. To the extent that these measures reflect the lengths of the hamstring and iliopsoas muscles, the findings support the notion of balance between the development of iliopsoas and ham-

TABLE 8.2

Correlation Matrix of Spinal and Pelvic Angles and Muscle Indices in Standing

Females	TK	LL	ST	PT	HI	II	LF
Thoracic Angle TK							
Lumbar Angle LL	-0.17						
Sacral Tilt ST	-0.24	0.81*					
Pelvic Tilt PT	-0.26	0.47*	0.43				
Hamstring Index HI	-0.12	-0.27	0.03	-0.22			
Iliopsoas Index II	-0.11	-0.55*	-0.34	-0.10	0.48*		
Lumbar Flexion LF	-0.06	0.66*	0.56*	0.35	0.08	-0.29	
Lumbar Extension LE	0.15	0.63*	0.72*	0.13	-0.17	-0.51*	0.33

Males	TK	LL	ST	PT	HI	II	LF
Thoracic Angle TK							
Lumbar Angle LL	0.08						
Sacral Tilt ST	-0.54*	0.77*					
Pelvic Tilt PT	0.39	0.40	0.25				
Hamstring Index HI	-0.47*	-0.33	0.05	-0.68*			
Iliopsoas Index II	-0.03	-0.56*	-0.51*	-0.46*	0.47*		
Lumbar Flexion LF	-0.09	0.41	0.55*	0.37	0.76*	-0.49*	
Lumbar Extension LE	-0.38	0.73*	0.81*	0.40	-0.05	-0.41	-0.24

* For 13 degrees of freedom, correlations greater than 0.44 and 0.59 are statistically significant ($p<0.05$ and $p<0.01$ respectively for a one-tailed test)

TABLE 8.3

Means and Standard Deviations of Lumbar Angles and Muscle Indices

	Males		Females	
	$\bar{x}$	s	$\bar{x}$	s
Hamstring Index	80.6	7.6	94.9	17.9
Iliopsoas Index	8.9	9.3	8.7	6.9
Lumbar Flexion	-21.3	7.1	-19.5	7.8
Lumbar Extension	38.4	10.9	52.6	11.0

string muscles in the healthy population. Thus, the combination of short hamstrings and by long iliopsoas (and vice versa) might be considered abnormal.

Finally, the iliopsoas index correlated negatively with lumbar extension - females with short iliopsoas tended to have a larger lumber angle in stance. This might be expected when it is recalled that the erect posture in human development is attained through a combination of hip extension and the development of the lumbar lordosis - if there is a limited capacity for either one of these to develop fully, compensatory development in the other might be expected in order that the erect posture be developed.

Although anthropometric measures of structures such as the long bones tend to correlate positively, if anything, mobilities between the trunk and hip and muscle lengths might be expected to correlate negatively.

Males. Only three of the statistically significant correlation coefficients were replicated. Lumbar angle correlated positively with sacral tilt. Pelvic tilt correlated negatively with the iliopsoas index and the hamstring index correlated positively with the iliopsoas index.

These findings provide further support for the model of posture described previously and a rationale for proposing and evaluating the design guidelines described below.

Standing

An evaluation was carried out to determine the effect of a foot-rest on posture. Table 8.4 presents mean pelvic tilts in each posture, with and without the footrest. Table 8.5 presents the results of an analysis of variance (ANOVA) of pelvic tilt of males and females in standing with and without a footrest.

As can be seen, placing one foot on a footrest reduces pelvic tilt in the neutral position. It appears to shift the range of pelvic tilt posteriorly, as might be expected if the iliopsoas muscle shortens (or is "released") by flexing the hip. Also, as demonstrated electromyographically, gluteal muscle activity is required to tilt the pelvis posteriorly in standing - the foot-rest may act to increase the mechanical advantage of this muscle. Subject sex did not have a statistically significant effect on pelvic tilt. All but one of the interaction terms was not statistically significant.

An exploratory analysis was carried out to test for the involvement of the iliopsoas muscle in postural adaptation to the foot-rest. The iliopsoas index was correlated with change in pelvic tilt in the neutral position (standing with and without the foot-rest). Pearson product moment correlations of -0.34 for females and -0.43 for males were obtained. The negative sign of the coefficients would indicate that use of the footrest causes

TABLE 8.4

Mean and Standard Deviation Pelvic Angles of Males and Females in Standing With and Without a Footrest with the Pelvis in Posterior (P), Neutral (N) and Anterior (A) Tilted Postures

	Females					
	P		N		A	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
No Footrest	88.2	6.2	97.9	6.7	111.5	6.3
Footrest	81.1	5.8	92.6	6.5	106.1	6.6
	Males					
	P		N		A	
No Footrest	86.7	4.5	97.5	4.9	112.9	6.6
Footrest	80.3	5.9	93.4	4.4	106.9	6.6

TABLE 8.5

F-Ratios from the Analysis (ANOVA) of the Effects of a Footrest on Standing Pelvic Angle in Neutral, Anterior and Posterior Tilted Postures

Factor	df	F-Ratio
Subject Sex	1, 28	0.00
Footrest	1, 28	173.3*
Sex X Footrest	1, 28	0.3
Pelvic Tilt	2, 56	526.9*
Sex X Tilt	2, 56	1.0
Footrest X Tilt	2, 56	3.6**
Footrest X Tilt X Sex	2, 56	0.8

* statistically significant, $p<0.01$
** statistically significant, $p<0.05$

greater posterior pelvic tilting in subjects with short iliopsoas muscles. However, the coefficients did not attain statistical significance. One possible reason is that the change in pelvic tilt when the footrest was used took place over a small range - the lack of variability in the data would tend to obscure any relationships.

Forward Sloping Chair with Kneepad

Spinal and pelvic angles were measured when subjects sat on a forward sloping chair and on a conventional chair. Four sitting positions were investigated - sitting erect, sitting with inclined trunk and the elbows on the front of the desk as if to write (using both a horizontal worksurface and one with a slope of 15 degrees) and reclining (with the trunk 15 degrees from the vertical). Because a backrest would have prevented measurement of spinal angles and since subjects were only required to recline for the time taken to make measurements, one experimenter supported the upper trunk of the reclining subject whilst the other took the measurements.

Table 8.6 presents mean lumbar and pelvic angles in each position and Table 8.7 the results of an analysis of variance (ANOVA) of the data. Chair type and body position both had significant effects on lumbar angle. The interaction term between chair type and body position was also statistically significant which suggests that the effect of one or more of the various body positions on lumbar angle depends on the type of chair used.

Table 8.6 indicates that, compared with a horizontal worksurface, the sloping worksurface had little effect on the lumbar angle of a subject leaning forwards onto the desk. Most of the postural

TABLE 8.6

Mean and Standard Deviation Lumbar and Pelvic Angles of Males and Females when Reclining (R), Sitting Erect (SE), Sitting with an Inclined Trunk (SI) and with a Sloping Worksurface (SIW) using Conventional (CC) and Forward Sloping (FSC) Chairs

		Males		Females	
		Lumbar Angle	Pelvic Angle	Lumbar Angle	Pelvic Angle
CC					
R	$\bar{x}$	-5.9	61.9	-1.5	60.3
	s	6.1	5.3	10.5	6.8
SE	$\bar{x}$	-3.0	83.9	2.0	86.1
	s	6.5	7.1	6.0	5.3
SIW	$\bar{x}$	-7.2	89.9	-3.9	93.5
	s	6.7	9.6	8.5	7.2
SI	$\bar{x}$	-7.8	93.8	-3.9	97.9
	s	6.7	7.9	8.3	6.8
FSC					
R	$\bar{x}$	9.1	70.7	15.7	70.6
	s	11.8	5.2	18.9	8.4
SE	$\bar{x}$	1.7	89.2	5.5	90.3
	s	10.5	6.6	7.0	5.8
SI	$\bar{x}$	-3.7	96.5	-1.1	100.1
	s	9.3	7.5	8.6	5.6
SIW	$\bar{x}$	-5.7	99.9	-1.3	103.1
	s	7.1	7.7	9.0	5.2

TABLE 8.7

F-Ratios from the Analysis (ANOVA) of the Effects of Chair Type and Body Position on Lumbar Angle

Factor	df	F-Ratio
Subject Sex	1, 28	2.79
Chair Type	1, 28	43.25*
Sex X Type	1, 28	0.01
Body Position	3, 84	21.77*
Sex X Position	3, 84	0.31
Chair X Position	3, 84	21.28*
Sex X Chair X Position	3, 84	0.31

* Statistically significant, $p<0.01$

adaptation seems to take place in the hip joints - the pelvis being less anteriorly tilted and the trunk more erect when the sloping worksurface is used. This result is not surprising and is in accordance with previous findings (e.g. Bendix and Hagberg, 1984, Bridger, 1988, Zacharow, 1988). Comparing sitting erect with sitting with the trunk inclined forwards onto a flat surface, it appears that the postural adaptation takes place in both the lumbar spine and hip joints. For both males and females and for both types of chairs, the lumbar spine flexes (indicated by the negative lumbar angle) and the pelvis tilts forwards (indicated by the increase in the values of pelvic tilt).

When subjects reclined on the conventional chair, most of the movement appeared to take place as hip extension - i.e. the pelvis tilted rearwards and the trunk followed, flexing slightly. This is in accordance with the findings of Andersson (e.g. Andersson, 1986). However, with the forward sloping chair, less hip extension occurred when the subjects reclined. Approximately one third of the postural adaptation took place in the lumbar spine as extension.

In an exploratory analysis, Pearson Product-Moment correlation coefficients between the iliopsoas index and change in lordosis (the difference in lumbar lordosis between erect sitting and reclining) were calculated. This was done separately for males and females and for chair type. For males, coefficients of -0.41 and -0.18 were obtained for the conventional and sloping chairs respectively. Neither correlation coefficient was statistically significant ($p>0.05$, $df=13$). For females, coefficients of -0.37 and -0.61 were obtained for the conventional and sloping chairs respectively. The latter coefficient was statistically significant ($p<0.01$). The negative sign suggests that postural adaptation to reclining on a forward sloping chair is influenced by the iliopsoas muscle, which limits rearward movement of the pelvis, that is, the pelvis is constrained anteriorly by the muscle. Subjects with short iliopsoas cannot tilt their pelves rearwards on the forward sloping chair - the rest of the adaptation therefore takes place as extension of the lumbar spine.

A number of authors have criticised the design of forward sloping seats with kneepads. A common criticism is that these seats do not have backrests or lumbar supports (Drury and Francher, 1985). It has been demonstrated that a backrest reduces disc pressure and electromyographic activity of the erectores spinae muscles of subjects using conventional seats (Andersson et al., 1975).

When sitting erect on a conventional seat, a lumbar support compensates for the loss of lordosis. It acts like a "brace" which uses the lumbar spine to tilt the pelvis forwards. This brings the lumbar spine close to or below the vertical axis of the trunk and reduces the flexion moment exerted on the spine (Corlett and Eklund, 1986). Forward sloping seats encourage a more anterior position by virtue of reduced hip flexion and forward slope. Thus, a lumbar support may be unecessary. When reclining, according to Corlett and Eklund, the lumbar spine flexes under gravity forces. Under these circumstances, a backrest prevents this "sag" and, by supporting the mass of the trunk, reduces tension acting on the posterior spinal ligaments and anterior wedging of the intervertebral discs.

It may therefore be <u>inappropriate</u> to recline when sitting on a chair with a forward sloping seat. If such chairs were fitted with backrests, this would have little effect on the erect sitting posture and, if reclined against, would tend to increase the lumbar lordosis in a posture of the body (reclining) in which a lordosis is usually absent. In individuals with short iliopsoas, it might cause excessive lordosis. Corlett and Eklund (1984) suggested that backrests are inappropriate on chairs with forward sloping seats because they increase the horizontal force component and destabilise the sitter.

The present findings support this conclusion, although for different reasons as outlined above.

Modified Industrial Stool

Stools are a commonly used form of seating in industry. The seat height of a stool is usually higher than that of an office chair to accommodate bench heights suitable for standing work. For this reason, footrests have to be incorporated into the design of the stool or the workbench.

Figure 8.1 depicts a prototype stool with a height-adjustable footrest. The footrest was adjusted to mimic the hip and knee posture of a forward sloping chair, placing the ankles below the ischial tuberosities.

Table 8.8 gives lumbar and pelvic angles of subjects sitting on the modified stool in posterior, neutral and anterior pelvic postures. A forward sloping chair with kneepad was used for comparison purposes. Table 8.9 gives the results of an analysis of variance (ANOVA) of the data.

As can be seen, a statistically significant difference in lumbar angle was observed between the sexes - females exhibiting larger lumbar angles than males. Seat type did not have a significant effect on lumbar angle although pelvic tilt did, as was expected

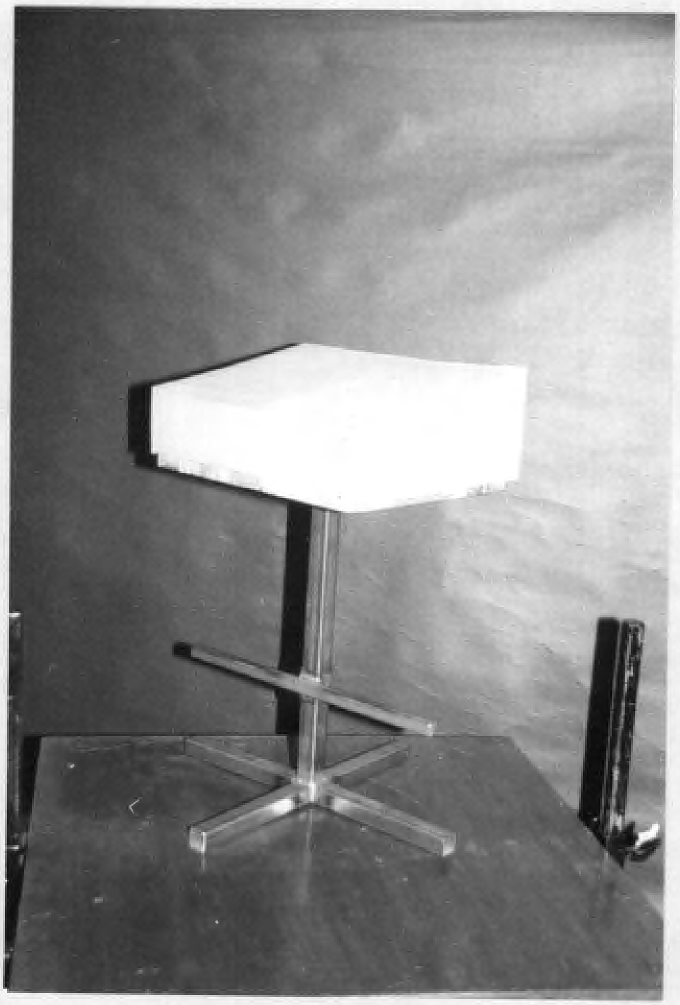


Figure 8.1 Stool with adjustable footrest.

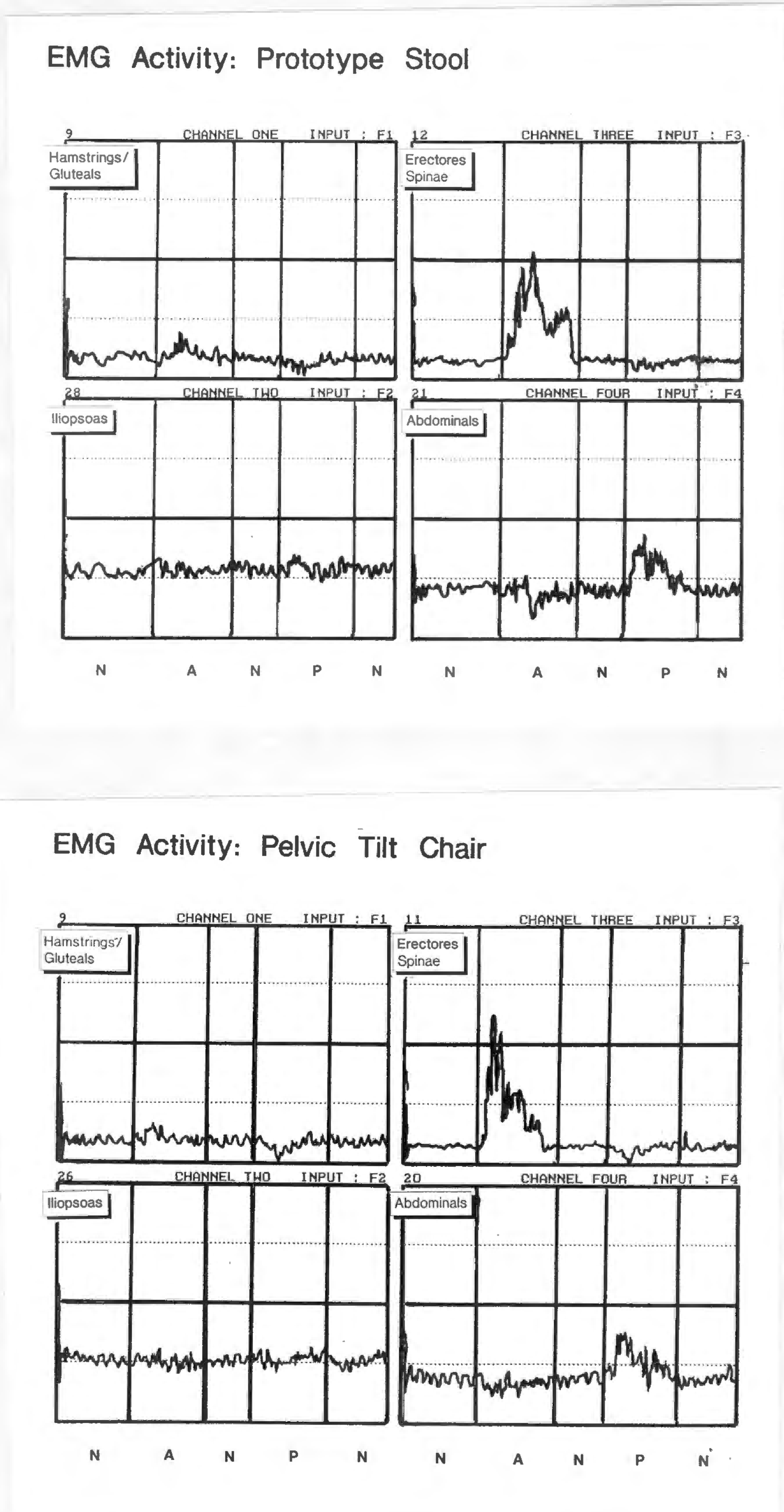


Figure 8.2 Electromyographic (EMG) activity from one subject executing posterior (P), neutral (N) and anterior (A) pelvic tilts in a modified industrial stool and a forward sloping ("Pelvic Tilt") chair.

from previous findings. None of the interaction terms were statistically significant.

Using the terminology used in the electormyographic investigation, it might be concluded that both types of seat place the sitter in the same "postural space". Figure 8.2, presents electromyographic (EMG) activity obtained from one subject, using the pelvic tilt methodology. As can be seen, the general pattern of activation is very similar in both seats.

An exploratory analysis of the effects of the footrest was carried out. Subjects sat on the modified stool at a worksurface adjusted to elbow height. Lumbar and pelvic angles were measured in erect sitting and with the the trunk inclined forwards and the elbows resting on the worksurface as if to write. This was repeated with the feet resting on a conventional footrest, situated underneath the worksurface, and with the footrest situated below the ischiia. Table 8.10 gives mean and standard deviation lumbar and pelvic angles for each of these positions. Analysis of variance suggested that knee flexion had a statistically significant effect on pelvic angle for males, but not for females ($F=7.00$, $df=1$ and 9, $p<.05$, F 0.22, $df=1$ and 5, $p>0.05$). However, the effect was small and was not accompanied by reduced lumbar flexion. A particular problem which was observed in the experiment was the frontal stability of the sitter when both legs were placed on the footrest situated below the feet. Under these circumstances, the base of support of the body is restricted to the seat itself. One method of compensating for the lack of frontal stability would be to shift part of the body weight posteriorly by means of a posterior pelvic tilt which would tend to increase lumbar flexion.

TABLE 8.8

Mean and Standard Deviation Lumbar and Pelvic Angles of Males and Females Sitting on a Modified Stool and a Foward Sloping Chair in Posterior (P), Neutral (N) and Anterior (A) Pelvic Postures.

		Modified Stool			Forward Sloping Chair		
		P	N	A	P	N	A
Males							
Pelvic Angle	$\bar{x}$	77.7	88.0	105.0	78.0	86.5	102.5
	s	5.5	5.6	5.2	5.3	6.3	6.5
Lumbar Angle	$\bar{x}$	-6.6	2.9	26.1	-7.8	0.5	22.3
	s	7.8	7.9	9.1	6.2	9.0	9.6
Females							
Pelvic Angle	$\bar{x}$	79.7	88.9	105.3	76.7	85.3	103.9
	s	5.6	5.0	6.2	7.1	4.8	6.1
Lumbar Angle	$\bar{x}$	-5.2	5.8	34.3	-5.8	5.4	29.9
	s	9.4	7.6	11.9	8.8	6.2	11.3

TABLE 8.9

F-Ratios from the Analysis (ANOVA) of the Effects of Chair Type and Pelvic Position on Lumbar Angle

Source	df	F-Ratio
Subject Sex	1, 28	4.61**
Chair Type	1, 28	2.79
Sex X Seat	1, 28	0.04
Pelvic Tilt	2, 56	221.68*
Sex X Tilt	2, 56	1.87
Chair X Tilt	2, 56	2.13
Sex X Seat X Tilt	2, 56	0.28

* Statistically significant p<0.01
** Statistically significant p<0.05

TABLE 8.10

Mean and Standard Deviation Lumbar and Pelvic Angles of Males and Females in Siting with the Trunk Erect and Inclined and Using Two Different Footrests.

		Knees Flexed		Knees Extended	
		Erect	Inclined	Erect	Inclined
Males N=10					
Pelvic Angle	$\bar{x}$	90.5	97.1	86.2	99.0
	s	5.6	8.5	3.3	6.3
Lumbar Angle	$\bar{x}$	-3.9	-7.3	-1.5	-5.0
	s	7.0	6.9	6.6	9.8
Females N=6					
Pelvic Angle	$\bar{x}$	88.6	102.2	87.7	102.7
	s	2.9	3.6	4.4	2.8
Lumbar Angle	$\bar{x}$	-1.7	-6.2	-0.33	-6.7
	s	5.9	6.1	5.9	9.8

Conclusions

A number of the statistically significant correlations in experiment 2 were replicated. The findings highlight the importance of the iliopsoas muscle in posture and, while not in disagreement with those of previous researchers as far as lumbar flexion is concerned, they place less stress on the hamstrings as a mechanism of postural adaptation.

The effect of a footrest on standing posture was found to be statistically significant - the average reduction in anterior pelvic tilt being approximately 4-5 degrees irrespective of subject sex. It is noteworthy, that for some subjects, reductions of up to 12 degrees were observed.

Sagittal movements of the trunk in the sitting position were investigated using conventional and forward sloping chairs. In theory, the trunk may be inclined anteriorly and posteriorly by flexing or extending the hip or the spine or both. In practice, a combination of the two would be expected - if the pelvis was constrained in a particular direction, more postural adaptation would take place in the spine. The findings with respect to forward inclination of the trunk and the effects of a tilted worksurface were in accord with those of previous research - most of movement occurs in the hip joint, the pelvis tilts forwards bringing the spine forwards with it. The sloping worksurface reduces forward tilting of the trunk but not necessarily lumbar flexion.

When reclining on the conventional chair, most of the movement took place in the hip joint as extension - as might be expected since this posture is unconstrained posteriorly (and from the work of Andersson described previously). However, on the forward sloping chair, a significant part of the movement took place in the lumbar spine as extension because posterior rotation of the pelvis is more constrained on this type of seat.

A modified industrial stool was evaluated in which, by means of a suitably positioned footrest, the hip/knee configuration of a forward sloping chair might be reproduced and thus the postural adaptation to the stool might mimic that to the chair. In erect sitting, this was found to be the case. Since the knee is not impeded on such a stool, the knees may be extended when reclining against a backrest, thus preventing excessive lordosis. In erect sitting they may be flexed with the feet stabilised by the footrest. When leaning forward the knees may remain flexed with the feet below the ischia to prevent excessive lumbar flexion. The concept, although promising, was found to pose problems concerning the anterior stability of the sitter and thus requires further investigation, beyond the scope of the present thesis.

9. GENERAL DISCUSSION

Evaluation of the Approach

It was not the purpose of this thesis to develop new methods of investigating working posture in ergonomics. However, methods and concepts not normally employed in ergonomics were used. These methods have been used successfully to test hypotheses about posture in other disciplines. Keegan (1953) and Mandal (1981, 1982) describe an anatomical framework for considering posture in ergonomics but their experimental approach has been largely qualitative. The abovementioned methods enabled this framework to be used in a quantitative manner.

The research was limited to a specific population and sample sizes large enough to test the main hypotheses were used. For population anthropometric purposes, the sample sizes would be small. The estimates of the various body parameters should not be interpreted in a normative manner although the relationships between the variables provide new insights into some general mechanisms of posture in healthy individuals

The error associated with the methods may have obscured some of the interrelationships between the postural variables. For this reason, a replication of the main findings was attempted and judged to be successful as far as the major conclusions were concerned. Statistically significant relationships between the variables were observed. These are consistent with the theoretical approach taken and with the findings of the few previous quantitative studies in this area.

The correlational nature of the data does not permit causal statements to be made. For example, it cannot be said that pronounced lumbar lordosis or anterior pelvic tilt in stance is caused by shortness of the hip muscles - the opposite might be the case, or other variables might be involved.

The present data do not represent posture or postural stress in a particular body position. Working posture is the combined result of the effects of several classes of variables at different levels of analysis (e.g. Mandal, 1982) - the visual and manual requirements of tasks, the characteristics of users and the design of workspaces themselves. Stress results from the imposition of load on the body in a particular posture. However, when changing position from standing, the basic configuration of the body parts must change. This represents the postural adaptation to the new position. In turn, this determines the range of postures and movements which are possible in the new position. Thus, the present data reflect the fundamental changes required for the body (particularly the spine and pelvis) to accommodate a particular position rather than the posture which would be adopted when carrying out a task in that position.

For these reasons, it would not be appropriate to base design guidelines, standards or regulations directly on the work presented here. Rather, the work provides a conceptual base for specific, goal-directed investigations of the reduction of postural stress through workspace design. As discussed previously, techniques and methods for the execution of such studies are well-established.

Anatomical Implications

A number of the findings of the present work are in agreement with those of previous researchers and are briefly discussed. Several authors have investigated the relationship between lumbar curvature and pelvic tilt. Walker et al. (1987) found no relationship between measures of these variables in a sample of young students and concluded that a variety of factors might be involved. The present findings are in agreement with this.

In a radiographic study of children and young adults, Voutsinas and McEwan (1986) found a significant positive correlation between sacral inclination and lumbar curvature. In the present research, lumbar angle was found to correlate with sacral tilt.

Thus, some of the variability in lumbar angle between subjects can be explained at the level of the sacrum but not at the level of the pelvis.

Walker et al. suggested that further investigations of lumbar curvature and pelvic tilt would be worthwhile. Such investigations might use several methods of investigating pelvic tilt and take each bilaterally (only unilateral measures were used in the present research). Additionally, investigations of the angulation of the articular facet of the sacrum would be of some relevance to the issue.

Pelvic tilt is not the only determinant of spinal curvature. Kapandji (1970) describes how the articular facet of the sacrum is subject to wide variation in humans. In the more horizontally aligned sacrum, the spinal curves are pronounced - Kapandji regards this as an over-adaptation to bipedalism. When the spinal curves are less pronounced, the sacrum tends to lie more vertically on the ilium. This may explain why measurements of pelvic tilt do not always correlate with measurements of lumbar curvature (Walker et al. 1987), whereas measurements of sacral tilt do. Although the more vertically aligned sacrum with flatter spine does occur in adults, it is more usually seen in children and more closely resembles the sacral orientation found in primates (Kapandji, 1970). Clarification of this issue would be of some importance both in the general study of posture development and for the use of pelvic inclination as an index of spinal curvature in those cases where the spine itself is obscured (e.g. when reclining against a backrest).

The findings of experiment 2 demonstrate great variation in lumbar angle across body positions (the thoracic curve varies less due to the support of the attached ribs). Body positions can be characterised in terms of the degree of pelvic constraint as well as the spinal angles. Long sitting and semi-squatting were the most constrained postures whereas standing and kneeling were the least constrained.

According to Nachemson (1966, 1968), the lumbar spine has little intrinsic stability and, in upright positions, is stabilised by the vertebral portion of the psoas muscles. The lumbar lordosis can thus be seen as an adaptation to standing which depends on the activity of these muscles.

This view is supported here by the negative correlation between the iliopsoas index and pelvic tilt in males and females. Individuals with small iliopsoas indices have greater anterior tilt in standing than those with large iliopsoas indices. In terms of the conceptual model described previously, pelvic tilt in relaxed standing represents an equilibrium position or a position of stress equalisation amongst the muscles overlying the pelvis. Hip flexion shortens the hip flexors and therefore weakens them whilst it lengthens the hamstring and gluteal muscles resulting in a new equilibrium position with increased posterior pelvic tilt. This was observed in the two long sitting positions. It was found that the iliopsoas index was the best predictor of change in pelvic tilt, in most of the body positions. Several authors (including the present author, Bridger, 1988) have attributed the reduction in lumbar lordosis in sitting compared with standing to "passive stretching" of the hamstrings caused by hip flexion. However, this is probably inorrect. The reduction occurs even for small movements of the hip which would be unlikely to stretch the hamstrings to any significant degree. An explanation in terms of decreased tension in the, now shortened, hip flexors and the attainment of a new equilibrium point seems more parsimonious.

This would also explain the increase in pelvic tilt, compared with standing, which was observed for all subjects in the "two point kneeling" (or "praying" position). An explanation is that the knee flexion required to attain this position shortens the hamstring muscles, thereby weakening them and reducing their ability to oppose the pull of the iliopsoas (unchanged compared with standing) resulting in increased anterior pelvic tilt for all subjects, irrespective of muscle length.

Finally, in extreme postures (e.g. long sitting) the muscles and tendons opposing further flexion of the hip joint probably begin to undergo mechanical stretching. Their antangonists being greatly shortened and weakened at this point, the result is a highly constrained pelvic posture.

It is illuminating to quote from Denniston (1935) as follows, "Posture is an active process and is the result of a great number of reflexes, many of which have a tonic character. The attitudinal as well as the righting reactions are <u>involuntary</u>".

In the working positions investigated here, it can be seen that each of the neutral postures falls between a range of possible positions and <u>conscious</u> muscle activity is required to tilt the pelvis anteriorly or posteriorly. It appears that in constrained positions (such as long sitting) greater muscular effort will be required to achieve small displacements from neutral than in unconstrained positions (such as kneeling). It might be hypothesised that occupational low back pain results as much from static spinal postures caused by constraint as from the degree of flexion/extension of the spine itself.

The experiments yielded much data of anatomical interest which is worthy of summary. For example, indices of muscle length of one leg commonly differed by as much as 15 degrees from the other in healthy subjects. One leg may have shorter muscles than the other in a given direction but not in the other direction. This was also found by Troup et al. (1968). Further, indices of muscle length do not necessarily correlate with those of spinal mobility - a fact which Troup et al. found surprising since most anthropometric measures (e.g. the lengths of long bones) usually do correlate with each other. One possible explanation is that a certain amount of joint movement is required to carry out activities of daily living - if one body part lacks adequate range, other parts increase their range to compensate.

Finally, the development of muscle imbalances is generally held to lead to postural deformaties (Kendall et al., 1967). Significant positive correlations between the muscle length indices were found in the present investigations. This replicates the findings of Toppenberg and Bullock (1990). The presence of large muscle indices in one direction and small indices in the other, does not seem to occur in healthy individuals.

According to Hewes (1957), man is capable of attaining over 1000 comfortable resting positions but only a subset of these is found in any particular population. Many postures are culturally determined. In Africa and Asia, squatting and long sitting are common postures almost never seen in western industrialised countries. Clearly, the conclusions of the present investigation are only applicable to the population from which the data were obtained - cross-cultural investigations would be required before generalising the findings. The existing ergonomics literature contains design guidelines based on a small number of postural stereotypes - whether these are appropriate for industries in developing nations, where the population habitually adopts different positions is worthy of further investigation.

The present findings indicate that, in individuals with longer muscles, more postural adaptation takes place in the hip joint than in the spine. The effects of age on posture and on postural adaptation might therefore be worthy of further investigation. According to Troup et al. (1968), age appeared to reduce lumbar mobility but not hip mobility. However, the mean age of their subjects was 21 years - a relatively young sample, as used in the present investigations. It might be expected that spinal mobility would decline with age - particularly at middle age and beyond, due to intervertebral disc degeneration, amongst other factors. It might be hypothesised that, as the mobility of the hip joints and the spine diminishes, so the range of positions that can be adapted to also diminishes. The size of the "postural spaces" in each position would also decline, increasing the constraint and therefore static loadings, of the lumbar spine and pelvis.

"Anthropometric fit" between workers and their workspaces would be of much greater importance under these circumstances and this would have a particular impact on western countries undergoing demographic ageing.

Whether loss of flexibility with age is inevitable or whether it is related to factors such as sedentary lifestyle is open to debate. Claims for the benefits of the retention of flexibility to prevent low-back problems might be investigated using the methods of the present research. Hypotheses for the effects of hip mobility exercises on hip mobility, posture and postural adaptation might be derived accordingly.

Ergonomic Implications

Progress in the design of workplaces depends to a large extent on the development of appropriate models of the worker and on successfully communicating this information to designers. Mandal (1982) criticised the design of chairs and desks arguing that although manikins (jointed, two-dimensional representations of the human form) may be appropriate for dimensioning workplaces to accommodate a wide range of users, they present designers with a superficial and potentially misleading model of the body. A mannikin has an infinitely mobile hip joint whereas a user does not. As described previously, such considerations led Mandal to propose that seats should slope forwards, based on the view that the hamstrings limit flexion of the hip joint.

The present investigations have extended the work of Mandal and his predecessor Keegan and have attempted to quantify the relationships which these authors considered important. Measurements of the muscle indices of healthy subjects have been made and related to indices of pelvic tilt and lumbar curvature.

The development of valid models of posture and postural adaptation is of major importance for the generation of guidelines for designers and for the drafting of regulations and standards. Designers usually have little training in anatomy or physiology and make their decisions as much on aesthetic grounds as on functional or scientific ones (Dorfles, 1987).

The status of basic knowledge in a particular domain has an important influence on the contents of standards and regulations. For example, in the South African Government Gazette (Department of Manpower, 1983) certain draft factory safety regulations are set out which include the following:

<u>Provision of Seats</u>

15. Every employer shall:

(a) provide suitable seating accommodation for every person whose work can efficiently be performed sitting;

(b) permit any person whose work is ordinarily performed standing to take advantage of any opportunity for resting which may occur, and for this purpose the employer shall provide adequate seating accommodation; and

(c) provide seats with suitable backrests where the nature of the work performed by persons is such that backrests can be used.

Scientific support for points (a) and (b) may be found as early as 1924 (see Vernon, 1924) and support for point (c) in Floyd and Roberts (1958) and elsewhere.

Notwithstanding the fact that only point (a) ultimately reached the statutes, the draft regulations are of interest because they reflect what is deemed to be important amongst the many aspects of workspace design which might have been drafted for inclusion.

It is noteworthy that the flattening of the lumbar curve which occurs when the hips are flexed was attributed to passive stretching of the hamstrings muscles by Keegan (1953), Floyd and Roberts (1958) and Mandal (1981, 1982). It is illuminating to quote from Floyd and Roberts (page 9) as follows:

"It is readily seen, by a simple demonstration, that the lumbar concavity cannot be maintained when the hamstring muscles are stretched beyond a certain extent. This limiting amount of stretch occurs in the sitting position when the angle between the thigh and the trunk is less than about 90 degrees and the knee is flexed and also when the angle between the thigh and the trunk is 90 degrees and the knee is extended. Thus the taller person, sitting on a seat which is at a low height in order to accommodate a shorter person is at a disadvantage in that he may not be able to attain concavity of the lumbar spine. In the extreme situation, he may be compelled to adopt a posture involving considerable lumbar convexity."

Through their influences on designers and manufacturers, standards such as these have had a major effect on the working lives of millions of people. At the time Floyd and Roberts drafted their standards, office chairs (and desks) were not usually height adjustable, being based on a simple wooden frame design (see Akerblom, 1954, for a contemporary illustration). However, many of the principles Floyd and Roberts derived from anatomy and physiology are widely applicable today and may be used in the design of workspaces with adjustable seat and worksurface heights both in offices and also in factories and vehicles.

Standing Posture and Lumbar Range of Motion

It is accepted here that seated work positions result in less fatigue than standing work positions. However, the provision of seats is not always appropriate. Singleton (1972) discusses some of the considerations in deciding between standing and sitting work. For example, reach is greater in standing than in sitting, less space for the legs is required, body mass can be used to exert forces and the legs are very effective at damping vibration.

A general outcome of the present research is the data on lumbar angles and lumbar ranges of motion in standing and in the various body positions investigated.

From experiment 1 it was argued that lumbar angles would always be less in sitting than in standing. It can be seen that the standing lumbar angle can be expressed as a percentage of the total range of flexion/extension of the lumbar spine (if maximum extension is taken as 100%, then the standing lumbar angle for males was 78.8% and for females 65.4%). In experiment 2, values of 68 and 66% were obtained. Any increase in lumbar angle, as in two-point kneeling for example, is a movement towards the extremes of lumbar extension in which the stresses described by Adams and Hutton (1985) might be hypothesised to come into effect.

This has several implications. Firstly it is hoped that the incidence of excessive or sustained lumbar lordosis in industry will receive more attention both in laboratory research and in field surveys. Investigations of the incidence of low back problems amongst standing operators would be of value together with more detailed analyses of posture and postural loading of the extended lumbar spine.

Comparatively little research of an epidemiological nature appears to have been carried out on this subject and little mention of it is made in the ergonomics literature.

For example, although design handbooks such as Woodson (1981) and Clarke and Corlett (1984) contain guidelines for the design of workspaces for standing operators, they are usually based on anthropometric data rather than an anatomical model of the standing posture (interestingly, Keegan made a similar criticism of chair design guidelines 30 years ago). Generally, rersearch on standing in ergonomics has been restricted to investigations of the effects of different floor materials (e.g. Zhang et al., 1991).

The present findings point to the hypothesis that extreme lumbar postures can occur in standing as well as in sitting (although extended rather than flexed). Future research might be directed towards the factors that increase the risk of excessive extension and the requirements for workspace design amongst standing operators.

For example, the effect of a footrest on standing posture was found to be statistically significant - the average reduction in anterior pelvic tilt being approximately 4-5 degrees irrespective of subject sex. It is noteworthy, that for some subjects, reductions of up to 12 degrees were observed.

Grieco (1986) suggested that postural fixity in sitting may be a cause of intervertebral disc degeneration because it degrades nutritional exchange in the intervertebral discs which is normally brought about by load changes above and below a threshold value. Intermittent use of a footrest by standing operators might also help to reduce postural fixity of the lumbar spine for the same reasons. In the short-term, it may reduce fatigue or discomfort.

In a survey of South African factories by the present author, under the auspices of a project funded by the Department of Manpower, it has been observed that footrests or footrails are rarely provided for standing workers such as fish filleters, apple sorters and packers, fruit inspectors and several categories of machine operators. This is particularly common in low-level agricultural/food processing operations which are labour intensive and task repetitive. Where footrests are provided in such tasks (usually through the fortuitous placement of supporting struts on benches) surveys suggest they are used.

A related problem is the lack of space for the feet at the base of machines. Foot ingress is often obstructed by metal cowlings provided either for safety or for aesthetic reasons. One consequence is that the operator cannot position his/her feet underneath the leading edge of the worksurface. This increases the task distance. In order to position the torso close to the leading edge of the worksurface, operators have been observed to dorsiflex the ankle joint so as to incline the entire body forwards such that the pelvic girdle rests against the leading edge of the worksurface. The lumbar spine then hyperextends to reposition the torso vertically.

Future research on standing posture might begin by investigating spinal angles and pelvic tilt and construct hypotheses concerning the effects of workspace design factors on these variables. For example, lack of space for the feet might cause extreme foot positions to be adopted. These may require movements at the hip which alter the spinal/pelvic alignment found in relaxed standing (e.g. external/internal rotation, adduction combined with flexion etc.). Although speculative, these suggestions are open to investigation.

Sitting Posture

Further insights were gleaned from experiments 2 and 4, in which the function of the lumbar lordosis as a specialised adaptation to bipedalism (and to standing-up as opposed to sitting-down) was demonstrated by the data on pelvic and lumbar ranges of movement.

In many erect sitting positions, the lumbar lordosis found in standing appeared to be an unphysiological posture for the spinal/pelvic linkage - subjects were not able to reproduce it by means of an anterior pelvic tilt when sitting. The angles of pelvic tilt and lumbar lordosis which were attained when seated subjects attempted to tilt the pelvis anteriorly were of lesser magnitude to those found in relaxed standing. The present data suggest that attempts to design furniture and workspaces which restore in the spine of an erect sitter a lumbar lordosis similar to that found in standing are likely to be unsuccessful.

Essentially the present findings enable the posture of the trunk to be discussed in an anatomically more realistic manner. That this has not always been the case can be illustrated as follows. In discussing the effects of a forward-sloping seat on posture, Corlett and Eklund (1986), in an otherwise close analysis of the anatomy of seating state:

".... a forward-sloping seat, which reduced the backward pelvic rotation by allowing the legs to slope downwards, and thus made the retention of full lumbar lordosis more possible."

Clearly, this is partly right and partly wrong if by "full lumbar lordosis" the lordosis found in standing is meant. It is partly wrong for the reasons stated above that effort is required in any sitting position to tilt the pelvis forward so as to restore the lumbar angle found in standing - in some sitting positions it is beyond the available movement range according to the present findings. It is partly right, however, in that a lordosis is often retained on such seats. In fact, as the data on lumbar mobility indicate, over approximately two-thirds of the total range of movement, the lumbar spine is extended, not flexed. The mid-point of the movement range is therefore a lumbar lordosis of approximately 10 degrees. This may be attainable on seats designed for the purpose but does not constitute a "full lordosis".

Taken as a whole, the present data are a contribution to knowledge about the functional anthropometry of the lumbar spine and further measurements, using a wider subject base are called for. Such data may have important practical uses in workspace design (some of which have been discussed previously). When communicating with designers and engineers, statements about posture may be put into anatomical perspective. For example, the effect of a footrest is to tilt the pelvis of a standing person rearwards - by an amount comparable to that which forward slope tilts the pelvis of a seated person forwards (of similar magnitude to the difference between sitting on a chair and sitting on a stool).

As stated in the introduction, ergonomists rarely use measures of central tendency as a basis for design guidelines (although they are commonly used to test hypotheses and characterise populations). Rather, guidelines are usually based on the fifth and ninety-fifth percentile values of a variable, the principle being to design so as to accomodate a range of users, rather than an "average" user.

The present research suggests that valuable insights for ergonomics may be gained by applying this principle to the investigation of muscle lengths and joint mobilities as well as the more familiar static and functional anthropometric variables.

10. CONCLUSIONS

Investigations of a wide variety of positions supported the hypothesis that body position determines spinal and pelvic posture. The effects of seat slope and hip flexion in sitting were shown to be independent and additive. A linear relationship between sacral and lumbar angles was demonstrated in standing and in several sitting positions.

Pelvic and lumbar range of motion were also found to be dependent on body position. It appears that positions can be characterised by the constraint they impose on the pelvis and spine as well as their effects on relaxed, erect posture.

Investigations of the mechanisms of postural adaptation suggested that the iliopsoas muscle plays a major role. The role of the hamstrings appeared secondary and was only apparent when the knees were extended or the pelvis was tilted forwards.

A number of the practical implications of the work were investigated at a preliminary level. It has been suggested that chairs with forward sloping seats should be fitted with backrests. The present findings contra-indicate this since forward sitting is already anteriorly constrained. Lumbar posture in standing appears to be a relatively extended and constrained position although postural fixity in standing can be avoided using a foot-rest.

In comparison to sitting, the literature on the ergonomics of standing is small. It appears that this is unsatisfactory and that the present findings provide a framework for a programme of research into problems of standing posture in the workplace. Of particular interest are potential problems of lumbar hyperextension and the requirements for the design of workspaces for the standing worker.

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